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MASK Basin 'B' Bank Wave Survey

by
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This report describes and discusses the results from the Maneuvering and Seakeeping (MASK) Basin wave survey test conducted in August of 1999. The purpose of the test was to determine the uniformity, long crestedness, beach reflection, and repeatability of the waves in the MASK made by the 'B", or short, wave maker bank. The tests were done using the test matrix for the follow on Mobile Offshore Base hydroelastic test, so the results could be used as incident wave data.

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ABSTRACT

This report describes and discusses the results from the Maneuvering and Seakeeping (MASK) Basin wave survey test conducted in August of 1999. The purpose of the test was to determine the uniformity, long crestedness, beach reflection, and repeatability of the waves in the MASK generated by the 'B', or short, bank wavemakers, with some repeat of May 1999 survey results. The tests were done using the test matrix for the follow on Mobile Offshore Base hydroelastic test, so the results could be used as incident wave data.

ADMINISTRATIVE INFORMATION

The Naval Surface Warfare Center, Carderock Division (NSWCCD), Seakeeping Department (Code 5500) performed this work. The Office of Naval Research (ONR 334) funded this work under Mobile Offshore Basing (MOB) Project (R2266) of the Global Surveillance/Precision Strike and Air Defense Technology Program (PE 0603238N) for FY1999, authorized by Work Request N0001498WX20578. The Naval Facilities Engineering Service Center (NFESC ESC51) administered the MOB Project for ONR.

INTRODUCTION

The Maneuvering and Seakeeping (MASK) basin is 230 by 330 feet[†] with a nominal 20-foot depth over much of its area[1]. A 35-ft deep, 50-ft wide trench runs along its south wall, opposite the 'A', or long, bank of wavemakers, for the full basin length. A bridge spans the basin, resting on tracks at each end. The bridge can be rotated to 44.5 degrees and translate to the center of the basin. A self-propelled carriage is suspended below the bridge, which can travel the entire bridge length. The carriage supports test personnel, along with data collection, recording, and analysis equipment.

Most models tested in the MASK are on the order of 20 feet long. As such, temporal and spatial variation of the wave field can be quantified by placing wave probes near the model. Typically, such variations, as well as, diffracted, radiated and reflected waves are ignored. The large Mobile Offshore Base (MOB) model interacts with a large portion of the wave field simultaneously. This requires a quantification of the temporal and spatial variation of the MASK wave field.

The MASK facility has pneumatic wavemaker with 21 domes spread along two adjacent walls. The domes are numbered consecutively starting with the northwest end of the long bank to the northeast end of the short bank. Domes 1-13 on the 'A' bank and Domes 14-21 on the 'B', or short, bank. There are sloping beaches along the opposite walls to absorb the incoming waves and prevent reflection. The absorption properties are frequency dependent. An additional concern is repeatability of the wave field given changing environmental conditions, e.g., barometric pressure, and relative humidity.

[†] 1 foot = 0.3048m = 30.48cm

The test is a follow up of a previous wave survey[2] done in May 1999. This test repeats some 'A' bank conditions, but focuses mainly on the 'B' bank. The test used the same regular wave test matrix as the upcoming MOB hydroelastic test to allow the wave survey results to be used as incident wave data.

The test used an array of wave probes and pressure gages to measure the wave field and dome pressure. Measuring dome pressure is a means to determine whether the pressure in the domes is a source of wave field variability. Other aspects of the wave survey addressed the issues of wave reflection.

TEST SETUP

The test setup focused the sensors on the area in the center of the MASK basin where the MOB model will be located. This is similar to the May 1999 survey. This test also used a pair of probes near each end of the bridge to get information along the entire length of the bridge.

Water depth and dome settings were same as for the MOB hydroelastic model test. The dome stabilizer lip immersion was set depending on the expected wave amplitude. The stabilizer lip immersion was a nominal 9.5 inches[†] (full up) for wave amplitudes 5 inches or less; 15 inch immersion for waves 5-15 inches; and 22 inches (full down) for waves greater than 15 inches. The log book contains the individual stabilizer lip height records.

The atmospheric conditions remained fairly constant during the test. Barometric pressure was 29.8 inches of mercury. Relative humidity changed from 38.0 to 64.5%, while air temperature changed from 67.2 to 93.5 degrees Fahrenheit (19.6-34.2 °C). Water depth changed less than an eighth of an inch over the course of the test. These conditions are similar to the May 1999 conditions but have a larger spread in temperature and relative humidity. All of these environmental parameters were measured throughout the test to minimize and determine their effect.

WAVE PROBES

The wave probe locations made use of existing rigging and booms. See Figure 1 and Table 1 for probe locations. Probe locations are referenced to an origin located at the corner of the basin wall behind the long, or 'A', bank and the inside edge of the beach facing the short bank, i.e., the north east corner. The X-axis is positive along the long bank towards the west, i.e., short bank. The Y-axis is positive along the beach towards the south, i.e., long bank beach.

A survey of possible bridge locations revealed three more easily accessible spots. These spots would require fabrication of more booms and rigging. For this reason they were subsequently not considered.

The capacitance wire probes were mounted on all existing eight-bridge locations. Four additional wire probes were mounted on the carriage to compliment the existing four sonic probe array. The four sonic probes were arranged in a 5-ft square array in the carriage moon pool.

[†] 1 inch = 2.54 cm

Probes H, 1, 7, and E are located from the west to east along the northern side of the bridge. Probes M, 3, 5, and C are the corresponding south side locations. Wire probes L and 11 were mounted on booms extending fore and aft from the carriage, i.e., western and eastern side of carriage, respectively. Wire probe 9 was mounted in-line with Senix 2 and 4 parallel to the short bank. Wire probe K was mounted in-line with Senix 1 and 4 parallel to the long bank. Positions for probes 1, 3, 5, 7, 11, and L were used on the May 1999 survey.

PRESSURE GAGES

Two different brands of differential pressure gages, Sensotec and Setra, were used to measure the dome pressures. Each pressure dome was tapped to install a pressure gage. The gages were located near the center of the dome longitudinally and on top closer to the wall side of the dome.

The Sensotec gages were located on Domes 3, 6, 8, 11, 16, and 19. The Setra gages were located on Domes 2, 4, 5, 7, 9, 10, 12, 14, 15,17, 18, and 20.

Domes 1, 13, and 21 did not have gages installed because these domes are typically not operated. The submarine pier and punt obstruct Dome 1 for larger waves. Dome 13 was not run to avoid reflections from the short bank. Dome 14 is a short bank corner dome and is not run to avoid reflections from the long bank. Dome 21 is inoperable.

The gage for Dome 17 was bad and replaced with the gage from Dome 3. Subsequent runs using the long bank did not measure Dome 3 pressure.

WAVEMAKER REPAIRS

Both wavemaker banks were examined for obvious damage and leaks focusing on Domes 10 through 12. Inspection revealed that the butterfly valves in the blowers had cracked welds on a fourth of the domes. Furthermore, there was a discrepancy between the inscribed valve angle on the shaft and the attached pointer. The inscribed mark varied between domes while the pointer was constant. Consequently, all of the domes had their valves reset to the same position and welded in place.

Due to the location of the butterfly valve, the valve angle was not set to zero to avoid disturbing the airflow near the duct bend. The valve was set by visually sighting into the blower so the valve followed the contour of the duct.

NSWCCD personnel checked the speed of the blowers. All blowers were within 5 rpm of the desired speed. Therefore, blower speed was not deemed the cause of dome pressure variation.

The flapper plate angles were measured for all the long bank domes. The flapper plates control the inflow and exhaust of air into and out of the dome. There are two flapper plates for each dome, one for each inlet duct. There was variation between domes and flapper plates on the same dome. The flapper plates were not adjusted, as the domes with the largest difference were not the trouble domes.

The long bank domes were examined for leaks and misalignment. Leaks were found on the wall side of Domes 5, 7 and 10. No attempt was made to plug the leaks, as calculations showed the need for a large hole to cause the pressure differential.

Furthermore, the domes are not all the same depth in the water as determined incrementally increasing dome pressure with the flapper plates at the inflow position and looking for blow under. Blow under is when air escapes under the front edge of the dome. If the domes were perfectly aligned, all the domes would experience blow under at the same time. This was not the case. However, the differences did not warrant remounting the domes to the basin wall. The occurrence of spray on some runs results from air escaping up the gap between the stabilizer lip and dome, rather than blowing under the stabilizer lip.

INSTRUMENTATION

The instrumentation for this wave survey was the same as for the May 1999 wave survey[2], except for the sonic probes. This survey made use of four Senix brand sonic probes, which have a programmable range and ping rate.

WAVE PROBES

The wave survey used a combination of capacitance wire probes and sonic probes. NSWCCD personnel made the capacitance wire probes following an in-house design. The probes are 36 inches long with a circuit box at one end. Two quarter inch threaded rods provide structural support. The wire probes were mounted to L-brackets that fit into the end of the long support poles.

The support poles are fiberglass, 16 feet long with a 2.0 inch outer diameter. Each pole had a three-foot extension added so the probe would contact the water. Cables connecting the probe to the data collection computer ran inside the pole and along the bridge to the carriage. The cables have connections at the top of the poles and at the carriage to allow movement of the pole and/or carriage.

The four sonic probes were attached to the carriage using wooden boards clamped to scaffolding crossing the moon pool. The sonic probes are Senix brand with 15-degree heads. The only carriage location used corresponded to carriage position #1 from the May 1999 survey. The Senix probes are accurate to better than 1% of range, i.e., 0.30 inches for 30 inch range.

The wire probes were calibrated over $\pm$ 12 inches before and after the test. The before test calibrations were done on the calibration stand. The post test calibrations were done in place. The wire probes are accurate to 0.15 inches over a 24 inch range. Repeated calibrations show no sensitivity to corrosion, algae or oil films on probe wires.

The wire probes were weakly non-linear over this range, with the greatest deviation at the extremes. A 4^{th} order polynomial calibration was used. The non-linear calibration coefficients were determined using the pre- and post-test calibrations. The mean value was removed before applying the non-linear calibration. See Table 2 for calibration coefficients. The sonic probes have adjustable calibration for different offset distances from the water.

PRESSURE GAGES

All pressure gages used are vented bi-directional differential gages with 4-20mA range. Six are Sensotec and twelve are Setra brand. The ranges on the Sensotec and Setra gages are ± 1 psig† and ± 2.5 psig, respectively. The error is 0.1% and 0.2% full range for the Sensotec and Setra gages respectively. The gages were calibrated by the manufacturer and came with National Institute of Standards and Technology traceable calibrations.

The current loop was necessary to maintain signal strength over the long cable runs. The current was passed over a 250-ohm resistor to convert current to a voltage. Tests indicated no signal loss over a 1000 foot cable. The maximum cable run was less than 400 feet. All the resistors were calibrated with a 250-ohm standard.

DATA COLLECTION

Dedicated computers collected the pressure and wave probe data. Both computers collected data on hard drives and backed up data to 100 Mb Iomega Zip drives. Digitization hardware in the collection computers consisted of Scientific Solutions, Inc. Lab Master AD-PGH analog-to-digital converter (ADC) expansion board with a 64 channel ADC expander multiplex board. The data are saved as two-byte integers. The resident in-house data acquisition software package, COLSEP95, was used to control the acquisition process.

The ADC is a single 12-bit successive approximation converter with a maximum throughput of 330 kHz. A programmable, precision gain amplifier in front of the ADC allows the input range to vary from ± 10mV to ±10V. Regular wave data were collected at 40 Hz; irregular wave data at 20 Hz; and pressure data were collected at 50 Hz.

Due to the nature of the digitization process an upper limit must be placed on the frequency range of a measurement to avoid aliasing. Individual, Precision Incorporated 6604-B-TD2A-BCM constant time delay filters provided the electronic filtering for each channel prior to digitization by the data collection computer. The filters have a 6-pole Bessel with 6 zeros characteristic with a 3.97dB attenuation at the programmed cut-off frequency. The filter cut-off, f_c, was set at 4 Hz for the wave data and 10 Hz for the pressure data. Filter attenuation reaches the traditional cutoff specification of –3 dB at a frequency of $0.86f_c$. The –70dB attenuation floor in the stop band is reached at $3.69f_c$.

The data collection computers were not specifically time synchronized. Run start and stop times are different between the two computers. A run log was used to keep track of the run numbers from each computer associated with a condition. Furthermore, pressure and wave data are stored in directories with different names.

The data were collected using linear calibrations. The non-linear calibrations of the wave probes were accounted for by post processing. The post processing took the collected voltages, calculated the correct engineering units using the 4th order polynomial calibration. The engineering units were converted back to voltages using a linear calibration consistent with current software.

† 1 pound/square inch gage (pisg) = 6.89 kPascals gage (kPa g)

TEST METHODOLOGY

The test used a reduced test matrix of wave frequency and steepness from the May 1999 survey. See Table 3 for the test matrix. The wave survey test matrix is almost entirely regular waves – 7 periods and nominally 3 steepnesses per period. Some irregular wave runs were made as well using the same spectra as used in the MOB hydroelastic test.

The wave periods range from 1.29 to 3.1 seconds. The steepnesses are nominally 1/30, 1/50, and 1/100. The wave survey used short and long wave packets to measure reflection and stationarity. Each condition was repeated at least three times to allow a measurement of uncertainty. Each condition had a long duration and a short packet run. For the long duration runs, the waves were generated until the reflection reached the wavemaker. The short packet run tried to avoid any overlap of the incident and reflected waves.

The beginning of the runs were harmonically analyzed to find the amplitude and phase of the first three harmonics. The time chosen was the first 10-30 seconds of steady state data after the beginning transient. This time window could include reflected waves depending on combination of probe location, wavemaker bank, and period. The short bank wavemaker runs required multiple time windows for data analysis because of the large distances between the probes. It is possible to be analyzing waves on one channel and noise on another if this is not done. The time windows attempted to capture the same waves at each probe by sliding the window in time based on the group velocity and distance between probes. The comparison metric is the fraction the standard deviation (σ) is of the mean harmonic analysis amplitudes, expressed as a percentage. This is the coefficient of variation (COV).

The data were analyzed using a 95% confidence band (2σ) for determining bad data points. The 2σ band was applied twice to the data recalculating σ each time. The distortion was measured as the ratio of the first harmonic amplitude and 1.414 times the root mean squared of the signal. This term is designated A1/RQ0. Wave data that had an A1/RQ0 ratio less than 0.95 were ignored. The pressure data did not use this criterion due to the true presence of a third harmonic on shorter period runs.

The harmonic analysis time window was shifted in time using the group velocity so the same waves would be analyzed at each probe for the short bank runs. The probe spacing relative to the long bank and longer runs did not necessitate multiple time windows. The time window for reflected wave analysis was the same time window used for incident wave analysis shifted to account for travel time. Using the same selection procedure on each run minimized the subjective part of picking the time slice to analyze. The careful attention to the time window helped maintain consistency in the data.

CREST AMPLITUDE UNIFORMITY

The spatial variation of the waves was determined by examining the signals of the wave probes. The signals were harmonically analyzed to find the amplitude and phase of the first three harmonics. Values for all probes were calculated. Only values that were less than 5% distorted from pure sine waves were compared as determined by A1/RQ0.

Crest amplitude uniformity relates to the constancy of the amplitude along the length of the crest. This gives the spatial variation of the wave amplitude. The crest amplitude is expected to decrease near the edges of the basin perpendicular to the wave crest. This is readily apparent on the long bank runs looking at probes H, M, and E. Probe C, while near the short bank, is high in practically every condition both long and short bank waves.

For the long bank there appear to be definite wave amplitude patterns for a given period. Normalizing the amplitudes by the average amplitude and averaging across conditions does show a pattern, see Figure 2. However, there is a lot of variability around the average value, and some conditions are very different.

Looking at the bridge probes in the center of the tank, the probes closer to the wavemaker had larger amplitudes. After discarding outliers, the average COV, expressed as a percentage, of all the probes averaged across all conditions is 7.95%± 1.72%. Looking at probes just in the tank center and just the Senix array, average COV of the probes averaged across all conditions is 7.28%±1.18% and 4.09%±1.32%, respectively. The tank center and Senix array values are lower than the May 1999 survey probably due to only testing at one carriage position. See Figures 3-9 for plots of long bank amplitude variation at different X locations for different periods and blower speeds.

The short bank did have a noticeable trend across test conditions, see Figure 10. Probes 3 and 5 are usually low together. Senix 1 and 4 and probe K are approximately equal and tend to be greater or equal to Senix 2 and 3, and probe 9. Probe H is almost always greater than probe M. All of this together gives a north-south bias with the northern probes measuring a higher magnitude than the southern ones.

For the short bank, the average COV, expressed as a percentage, of all the probes averaged across all conditions is 8.37%± 2.02%. Looking at probes just in the tank center and just the Senix array, average COV of all the probes averaged across all conditions is 7.99%±2.16% and 5.04%±2.61%, respectively. See Figures 11-17 for plots of short bank amplitude variation at different X locations for different periods and blower speeds.

Of some concern are the seemingly large gradients in amplitude between probes, e.g., 0.9 inch difference between Senix probes. The difference between maximum and minimum over the average has values 2-4 times the COV, i.e., standard deviation to average. When the actual slope is computed, the angles are less than 1 degree. This explains why visual observations did not notice these trends.

The irregular sea root mean square (RMS) for each probe was compared with the wave amplitude pattern from the regular wave tests, see Figure 2. The irregular sea spectrum had a modal period of 2.56 seconds. Despite the closeness in period to 2.58 data, the irregular sea data do not follow same wave amplitude pattern. The spatial variation of the irregular seas data is the same as the regular wave data averaged over condition. The individual probe values are normalized by the average value for that condition. This makes sense because the irregular sea spectrum contains many periods other than the modal period.

WAVE AMPLITUDE UNIFORMITY

Wave amplitude uniformity measures the variation of the wave height from cycle to cycle. Cycles were determined by looking at slope changes in the time histories. Wave height is the difference between peak and trough. The cycle analysis used the same time window as the harmonic analysis. The cycle analysis was checked with manual time history analysis and repeated single cycle harmonic analysis. COV is the analysis metric.

The probes compared were the carriage wire probes to avoid sonic dropouts. Outliers were discarded based on 2σ criteria. The average COV of the carriage wire probes averaged across all conditions and both long and short banks is 0.048 ± 0.018. This number is similar in magnitude to the variation between runs for a given condition.

Repeated harmonic analysis yielded a COV that was typically less than the cycle analysis. For the 1.55 second, 575 rpm test case with the carriage wire probes, the average harmonic and cyclic COVs were 0.062 and 0.076, respectively. The standard deviation of the difference was 0.013.

WAVE LONG CRESTEDNESS

The spatial variation of the wave crest, or its long crestedness, was determined by comparing the measured to analytical phase angles. The reference probe is wire 9 and Senix 1 for the short and long banks, respectively. See Figures 18–31 for phase angle variation by probe for different periods.

The standard deviation of phase angle for each probe for a given period and blower rpm was very low, on the order of 1-3 degrees. The acoustic probes have smaller standard deviations than the wire probes. Combining all the runs for a given period, the standard deviation increases to 3-5 degrees. Wire probes 3, 5, 7, and 11 are towards the upper end of the scatter range. The end of the bridge probes, H, M, C, and E, have more scatter between runs and blower speeds than the other probes, e.g., over 100 degrees. The scatter at the ends of the tank is not of great concern given the known distortion in those areas. Also the short bank phase angle analysis only used the time window for the Senix array. As a result probes far from the center of the tank could be measuring transient behavior increasing the error above three dimensional distortion effects.

The phase angle scatter is less than the May 1999 survey[2]. This is probably a result of tack welding the butterfly valves. Re-analysis of some of the May 1999 data confirmed the original analysis. This indicates the improvement is not due to a change in analysis technique.

The measured phase angle had an average difference of near 12.5 degrees for both the long and short bank when compared with the analytical predictions. The average standard deviation of the differences between measured and predicted are 12.8 and 9.7 degrees for the short and long bank, respectively. The maximum difference was 47.8 degrees. Despite the large maximum difference, the low average differences indicate close agreement with the linear dispersion relationship and a longcrested assumption.

The data did show a definite phase difference between the sonic and wire probes. Examining the time histories showed the sonics to lag the wire probes. The phase difference in terms of a time difference had an average value of 0.087±0.021 seconds. As the periods increase, this time lag becomes less noticeable in terms of phase angle.

REPEATABILITY

Repeatability is measured from run to run and survey to survey by examining the wave amplitude at each probe. The same wave amplitude pattern should repeat in both cases. The COV of amplitudes at each probe as percentage, averaged over all tested conditions and probes, after removing outliers, is 2.04%±1.43% and 1.95%±1.14% for the short and long bank, respectively. Removing the outliers did not affect the mean much, but did reduce the standard deviation.

Wire probe #1 had an average COV as percentage of 9.77% for the short bank data. The run data show typically close agreement between most of the runs for a given condition. The remaining one or two runs would be not be classified as outliers, but would significantly increase the scatter. This error probably results from not carefully repositioning the probe between shifts.

The data for this wave survey were compared with data from the May 1999 survey for the same conditions. Both sets of data followed the same trends in terms of wave amplitude and in many cases lied directly on top of each other. There was less temporal variation than spatial variation. See Figures 32- 34 for examples of amplitude variation between the wave surveys.

The irregular wave time history repeatability was demonstrated by comparing a run made at the beginning and end of a test shift. The same wavemaker signal was used for both runs. Overlaying the time histories showed the waves were the same at the beginning and end of the run at all the probes. This showed repeatability of the wave generation signal as well as the spatial pattern repeatability.

Beyond the blower speed and frequency, pneumatic wavemakers are subject to changing environmental conditions. The environmental conditions are: barometric pressure, air temperature, relative humidity, water depth in the basin, and dome door and lip settings. The environmental conditions were fairly constant throughout the test and should not add any noticeable variability as noted by the repeatability of dome pressures.

WAVE REFLECTION

The reflected waves were measured by harmonically analyzing the time window that would correspond to the incident wave time window, accounting for wave group velocity and distance traveled to and from beach. As the reflection was usually not very sinusoidal, this survey compared standard deviations of the signal rather than harmonic amplitudes. The measured reflection is not pure beach reflection because it contains reflections from the tank walls, wavemaker shut off transients and has directionality associated with it. So the measurement is of tank reflection rather than only beach reflection and the numbers here are slightly higher than if only beach reflection were measured.

The measure of merit was the ratio of reflected and incident standard deviations for the corresponding time windows expressed as a percentage. The time window used for the beach reflection corresponds to the window used for harmonic analysis of the incident wave allowing for group velocity and travel distance. The values for the Senix array were used for comparison in an effort to reduce scatter.

The general trend was a decrease in beach reflection coefficient with increasing blower speed. There was no consistent trend with respect to period, other than the values were largest for 2.06 sec waves. Beach reflection was fairly consistent between long and short bank for periods less than 2.58 seconds. The long bank beach reflection from May 1999 survey was also consistent with the short bank beach reflection except for periods 1.81, 2.06, and 3.1 seconds. The difference could be a result of different probes locations and stricter data window selection. See Figure 35 for a plot of average beach reflection by condition.

The trend with blower speed indicates the reflection is not proportional to the incident wave. The reflection increases less rapidly than the wave height. The larger reflection at 2.06 seconds indicates a lesser efficiency or resonance of the beach at that period.

The average beach reflection averaged across all conditions for the Senix array is 9.81%±3.88% and 9.86%±3.42% for the short and long bank, respectively. Comparing all probes in the same manner gives very similar answers, 9.68%±2.53% and 10.68%±4.21% for the short and long bank, respectively. The fact the numbers are so close indicates a uniform reflection across the tank.

Other beach reflection measurement methods were impractical. Rigging concerns prevented running the carriage at the phase speed and performing spectral analysis on the signal to separate out components. Variability amongst the probes made using a wave probe array unfeasible.

PRESSURE UNIFORMITY

The May 1999 wave survey[2] revealed that Dome 10 was consistently 8% less than the mean value. As a result, the wavemaker domes and blowers were examined for mechanical failure, leaks, and other inconsistencies. The **WAVEMAKER REPAIRS** section describes the work done on the wavemakers.

The pressure dome measurements provide a measure on the primary source of spatial non-uniformity in the wave field. Having a direct measure allows for the quick correction of the problems identified.

The long bank still exhibited the same trends in terms of pressure amplitude as the May 1999 survey. Dome 9 is around 5% higher than the average and Dome 10 is 5% less than the average. Dome 12 also appears low, but this could be attributed to end effects. Dome 2 is consistently very low, whereas before it was acceptable, albeit sometimes low. See Figures 36– 49 for pressure variation by dome for both long and short banks. Note Dome 3 missing from plots due to a bad gage.

The fact Dome 2 is now low could indicate that the butterfly valve was mis-set during the repair.

The short bank dome pressures were low on the ends with no constant area near the center. This curved shape was consistent throughout all the conditions tested. The average dome pressure ranged from 96.4 -102.8% of the average short bank value.

HARMONIC CONTENT

The harmonic content of the pressure signals was not purely sinusoidal. For the shorter periods, there was a third harmonic component of comparable magnitude to the first harmonic amplitude. This third harmonic component disappeared as the period increased, disappearing completely by 2.58 seconds. This higher harmonic was not noticeable in the wave signal as measured by the high A1/RQ0 ratio for these runs.

PRESSURE PHASE

Dome pressure phase angles were not a major concern given all the blowers are driven from the same drive signal. The measurements bear this out. For the long bank the phase angles were all within 5 degrees of one another for all conditions. The same was true for the short bank except Dome 20, which consistently had values of –11 degrees.

UNCERTAINTY DISCUSSION

The uncertainty of the wave measurements results from variation in the wave amplitude from run-to-run and cycle-to-cycle, calibration curve fit accuracy, probe movement in waves, meniscus effects on the wire, data collection and sampling error. **WAVE AMPLITUDE UNIFORMITY** discussed cycle-to-cycle variation. **REPEATABILITY** discussed the run-to-run variation.

The 4th order polynomial had an average standard error estimate[3] of 0.15 inches. This is the error due to using a curve fit to the calibration rather than actual data for the measurement. The average percent error for the curve fit is 1.98%. Movement of the wire probes due to waves during testing produced a change no greater than 5mV as determined by shaking the probe on the calibration stand. This corresponds to an average change of 0.02 inches. The average percent error due to probe movement is 0.39%. It is assumed meniscus effects are of similar magnitude. The Senix probes are accurate to ±0.035 inches over their entire range.

The other precision error comes from data acquisition and sample rate. The test used a 12 bit analog-to-digital converter and saved the data as 2 byte integers. This gave the data a resolution of ±0.01 inches (0.20%), and ±0.0005 and ±0.001 psi for the Sensotec and Setra gates, respectively.

The phase angles are subject to a precision error due to sampling rate. The sample rate, 40 Hz, accounts for an error of 360/(40*period) degrees, or 7 – 3 degrees for the periods tested.. This is approximately equal to the run-to-run standard deviation of 3-5 degrees.

The harmonic analysis removes bias errors due to non-zero mean values for the probes due to water level changes and boom movement.

The uncertainty of the wave amplitude is ±5.6% and ±5.3% for the wire and sonic probes, respectively. The majority of the uncertainty comes from variation of the wave amplitude within the analysis time window, 4.8%. The uncertainty was found taking the square root of the sum of the squares following Reference 3.

The precision error on the pressure gages is given by the published values. The Setra gages had a noticeable bias error for mean values. These were removed by subtracting the means from zero runs with the blowers off.

CONCLUSIONS

This test surveyed the wave quality of the MASK at the expected test location for the MOB model. The test evaluated the wave quality in terms of crest uniformity, long crestedness, wave reflection, and repeatability. Additionally, the dome pressures were measured to help reveal error sources.

The pressure measurements reveal a consistent trend in dome pressure and phase angle. Dome 10 is consistently low by 5 percent of the average value. Surrounding Domes, 9, 11, and 12 also show more deviation than the other domes.

The wave amplitude COV in the tank center for both banks is 7.6%. The phase angles reveal long crested waves for periods tested in this survey, 1.29 to 3.1 seconds. Reflected waves averaged 9.8% of the incoming waves for all conditions.

The average variation between runs was 2% of the average value. It is possible to reproduce irregular seas time histories. The irregular sea RMS values follow the average of all conditions regular wave amplitude pattern, showing repeatability in spatial pattern. The data from both wave surveys were consistent showing temporal repeatability.

The wavemaker repairs seem to have improved the longcrestedness of the waves by reducing the phase angle scatter. Dome 2 may need to be adjusted to its original butterfly valve setting, rather than making it consistent with the rest of the domes. Dome 10 leakage is the next place to look for reducing the pressure drop.

Analytic predictions would give an idea of the best wave pattern that could be generated. Comparison with analytic predictions would show how much of the variation seen is to be expected and what to change to improve the wave pattern. The analytic predictions can also guide further work on the wavemakers to improve wave quality.

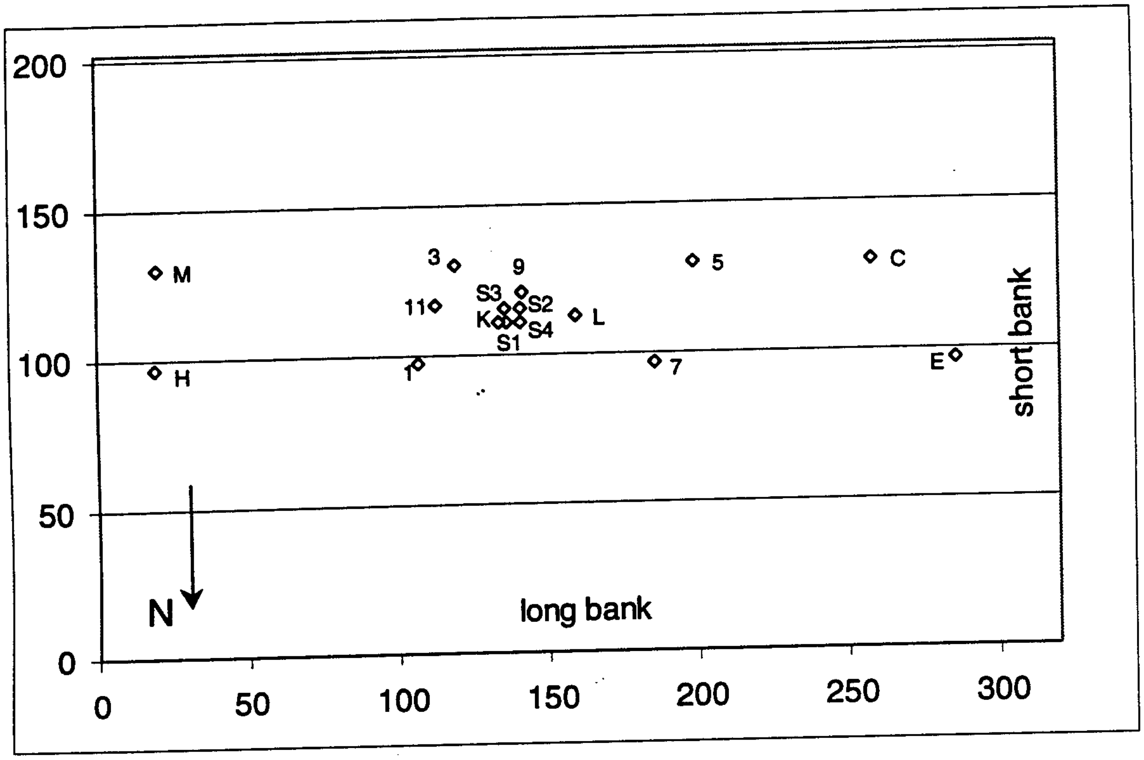

Figure 1. Whole basin view of probe locations (XY) in feet.

Table 1. Probe locations (XY) in feet.

Probe	X (ft)	Y (ft)
Senix 1	136.0	110.5
Senix 2	141.0	115.5
Senix 3	135.9	115.5
Senix 4	140.8	110.6
Wire 11	112.7	116.5
Wire 9	141.4	120.9
Wire K	133.4	110.6
Wire L	159.5	112.9
Wire H	19.3	97.0
Wire M	19.5	130.1
Wire 1	106.8	97.6
Wire 3	119.3	130.1
Wire 7	185.9	97.0
Wire 5	199.1	129.9
Wire E	285.6	97.0
Wire C	258.3	129.9

Table 2. Wire probe non-linear calibration coefficients.

Probe	C0 (in)	C1 (in/volt)	C2 (in/volt^2)	C3 (in/volt^3)	C4 (in/volt^4)
Wire 11	-0.10079	3.8939	-0.37978	-0.01172	0.00685
Wire 9	0.01533	4.5031	-0.48772	0.02193	0.00225
Wire K	0.04827	3.5685	-0.26140	0.01308	-0.00007
Wire L	0.03344	3.6022	-0.25926	0.01691	-0.00192
Wire H	0.03074	4.0110	-0.41378	0.04654	-0.00387
Wire M	0.04077	3.9405	-0.47967	0.11277	-0.01408
Wire 1	-0.07878	4.3693	-0.47954	0.03977	-0.00031
Wire 3	0.00213	3.9971	-0.36907	0.06161	-0.00872
Wire 5	0.08862	4.3160	-0.39466	0.02420	-0.00187
Wire 7	-0.03511	4.2622	-0.46204	0.02835	0.00215
Wire E	-0.04494	4.3315	-0.47562	0.00495	0.00719
Wire C	-0.06102	4.2991	-0.41822	0.03797	-0.00389

Table 3. Test matrix showing desired wave slope over measured wave slope by period and nominal blower speed.

(a) Short bank conditions.

	Blower speed		
Period (sec)	Low	Medium	High
1.29	100/31.8	50/18.8	
1.55	100/60.1	50/35.5	25/15.8
1.81	100/122.2	50/47.2	25/14.6
2.06	100/144.2	50/53.2	25/20.2
2.32	100/81.6	50/37.6	25/19.5
2.58	80/65.7	50/38.6	25/17.3
3.10	100/105.9	50/39.3	30/24.4

(b) Long bank conditions.

	Blower speed		
Period (sec)	Low	Medium	High
1.29	100/34.7	50/20.3	
1.55	100/57.9		25/17.5
1.81	100/136.6	50/52.8	
2.06	100/148.2		25/21.9
2.32			25/22.4
2.58			25/20.2
3.10		50/52.4	30/29.2

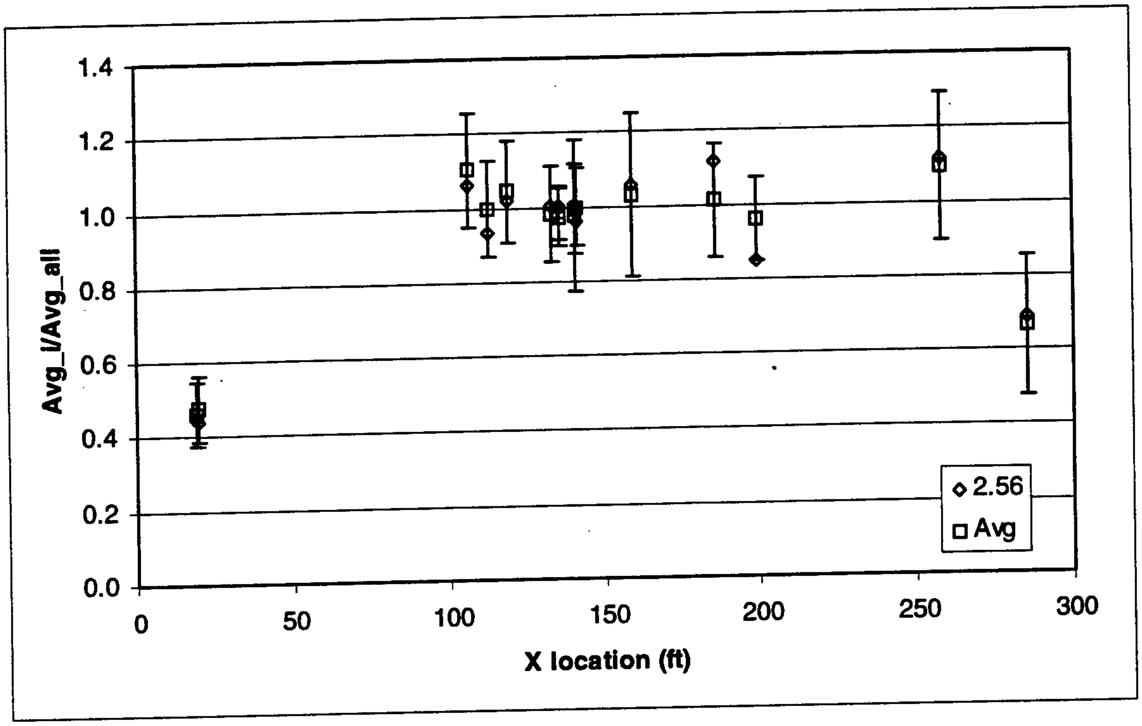

Figure 2. Normalized average wave amplitude averaged over all conditions for 'A' bank with 2.56 second modal period irregular seas data and 2σ error bars.

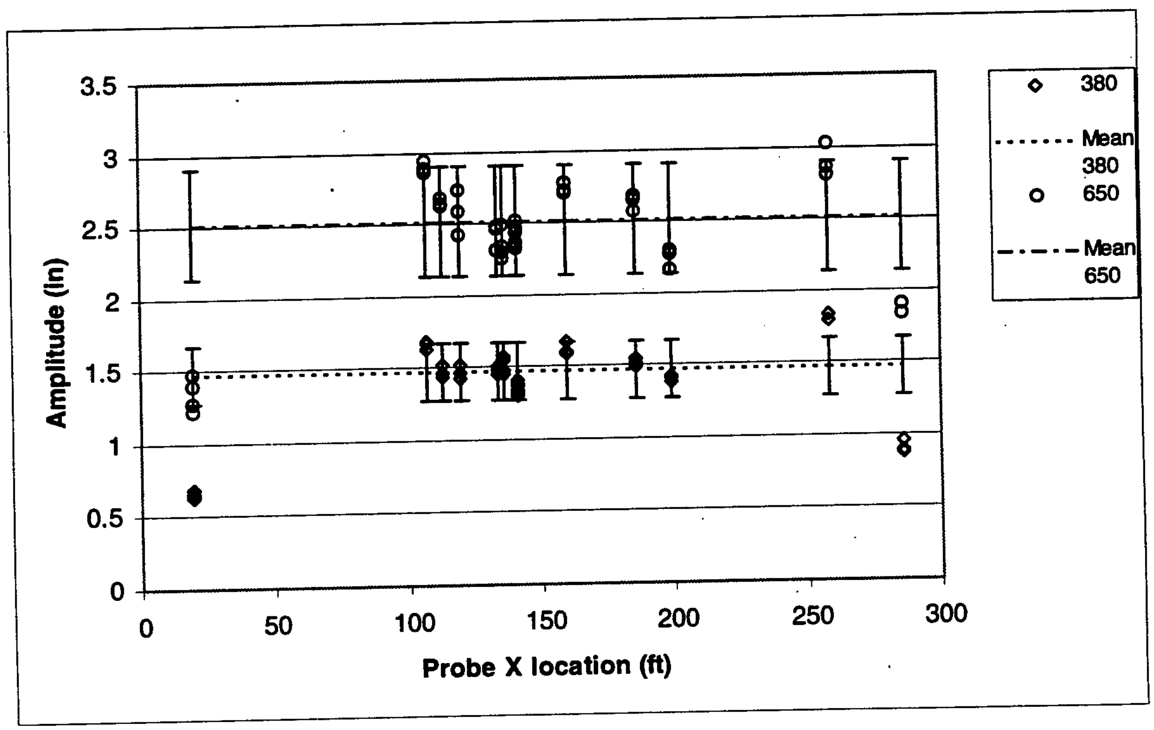

Figure 3. Wave amplitude by probe location and blower speed (rpm) for 1.29 seconds on 'A' bank.

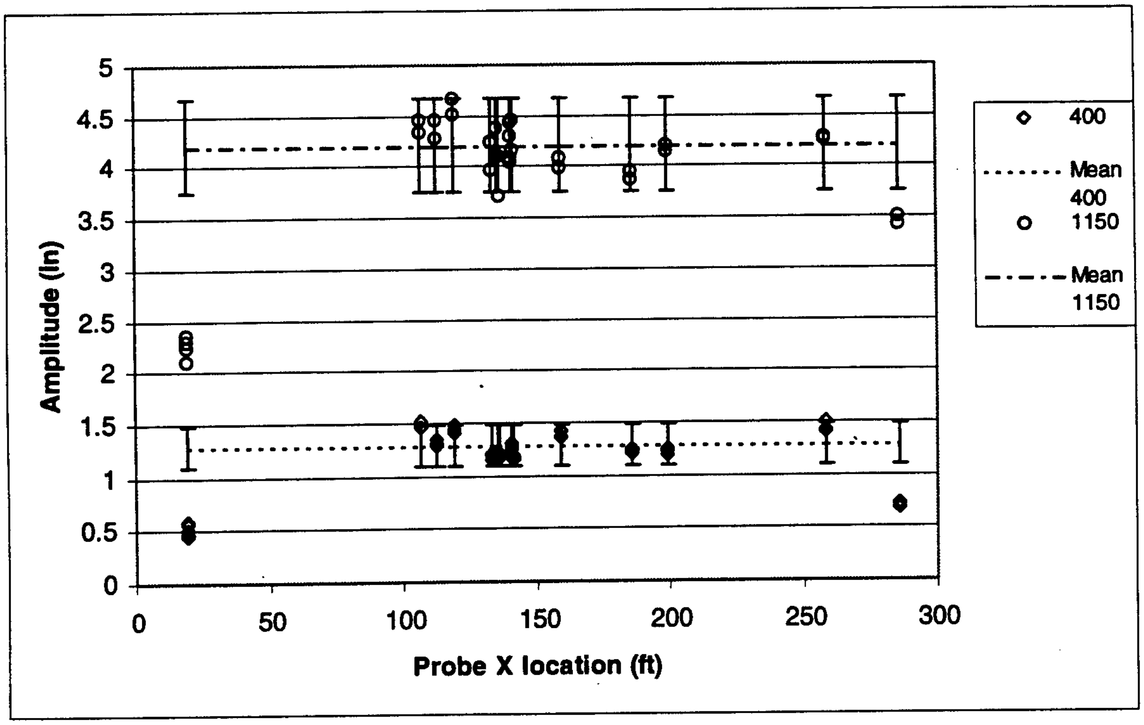

Figure 4. Wave amplitude by probe location and blower speed (rpm) for 1.55 seconds on 'A' bank.

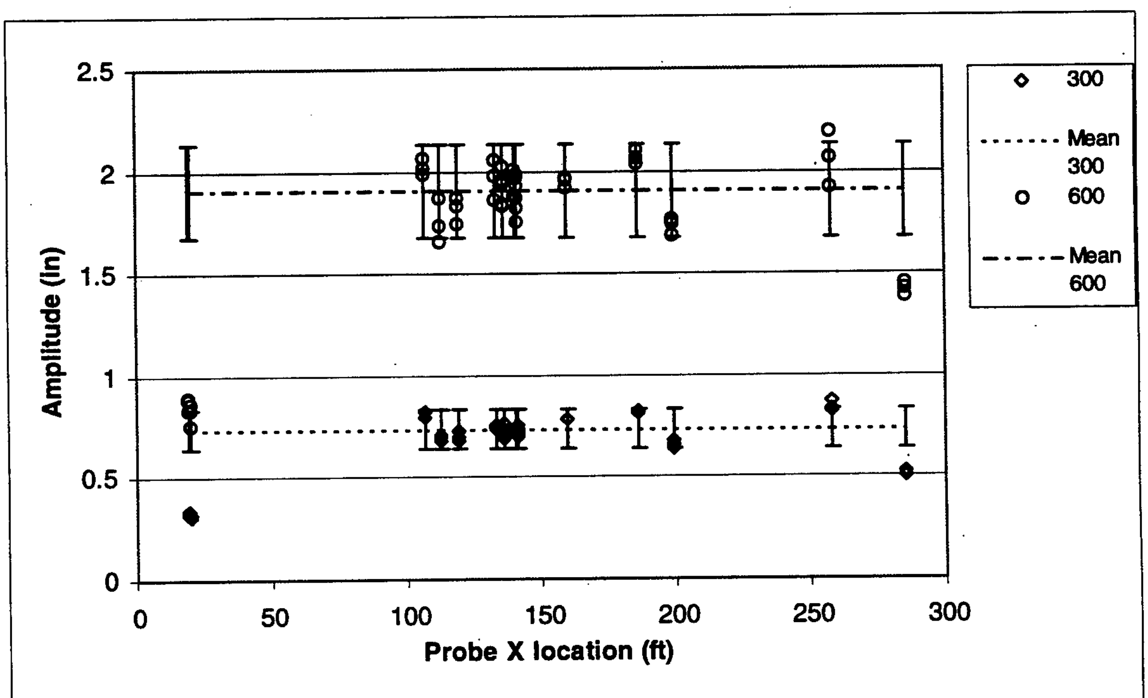

Figure 5. Wave amplitude by probe location and blower speed (rpm) for 1.81 seconds on 'A' bank.

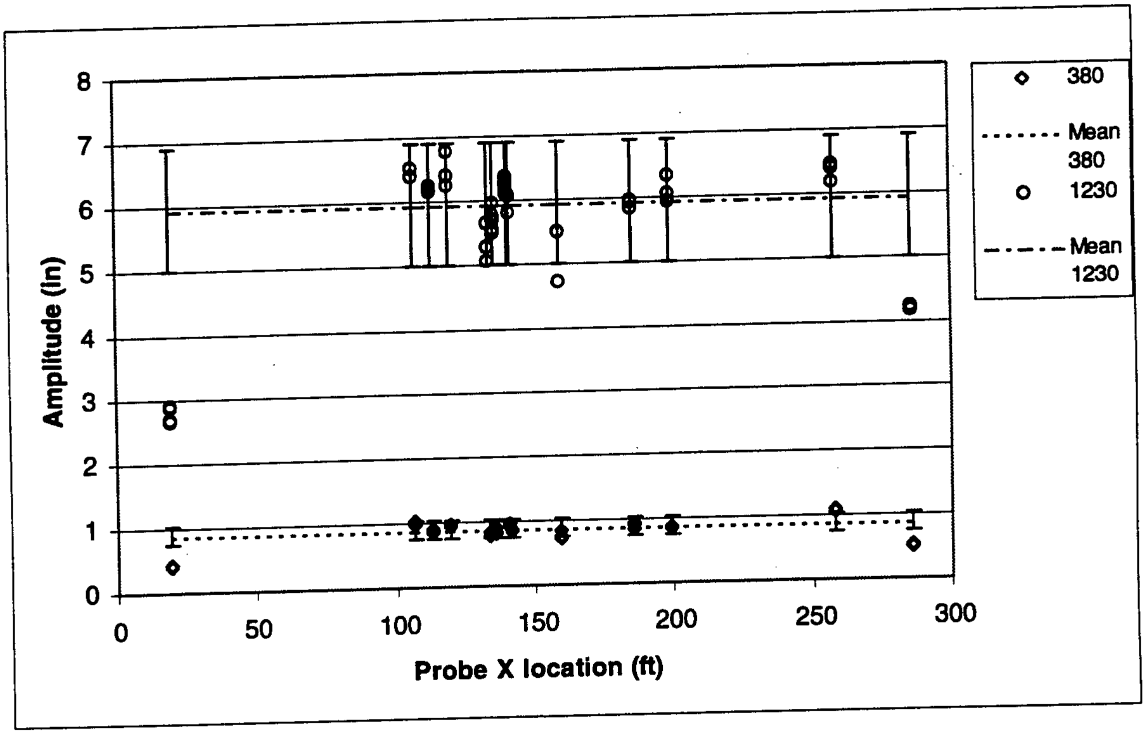

Figure 6. Wave amplitude by probe location and blower speed (rpm) 2.06 seconds on 'A' bank.

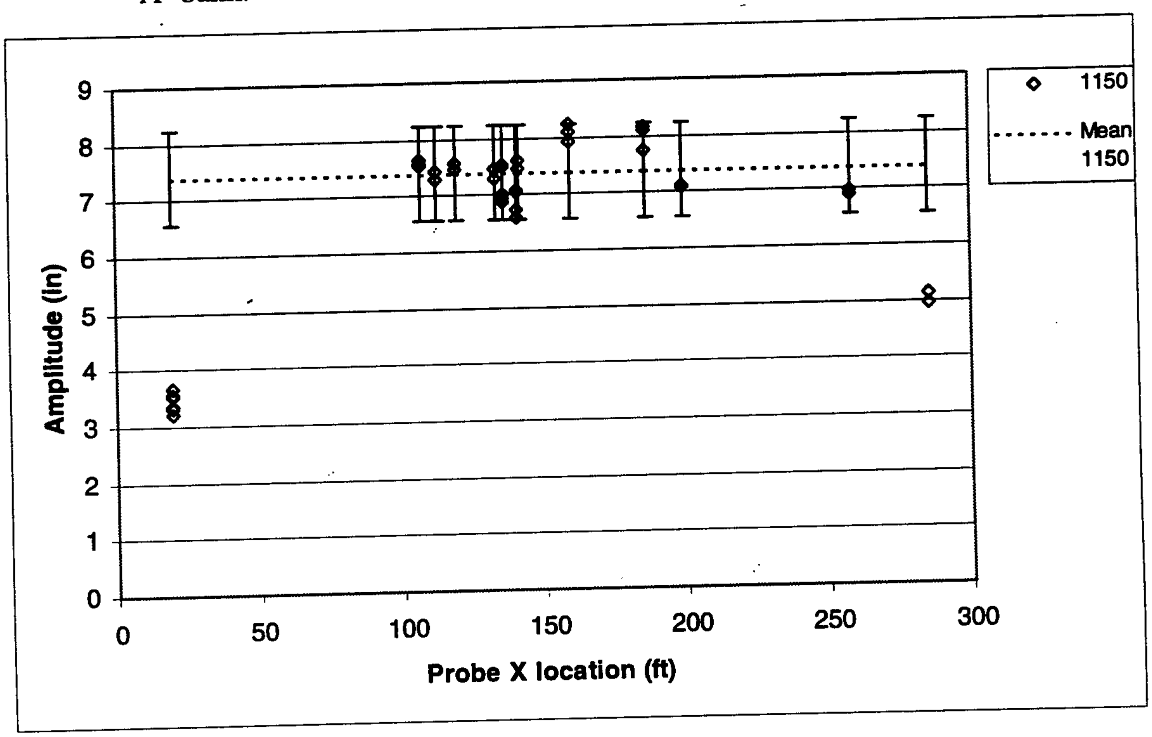

Figure 7. Wave amplitude by probe location and blower speed (rpm) at 2.32 seconds on 'A' bank.

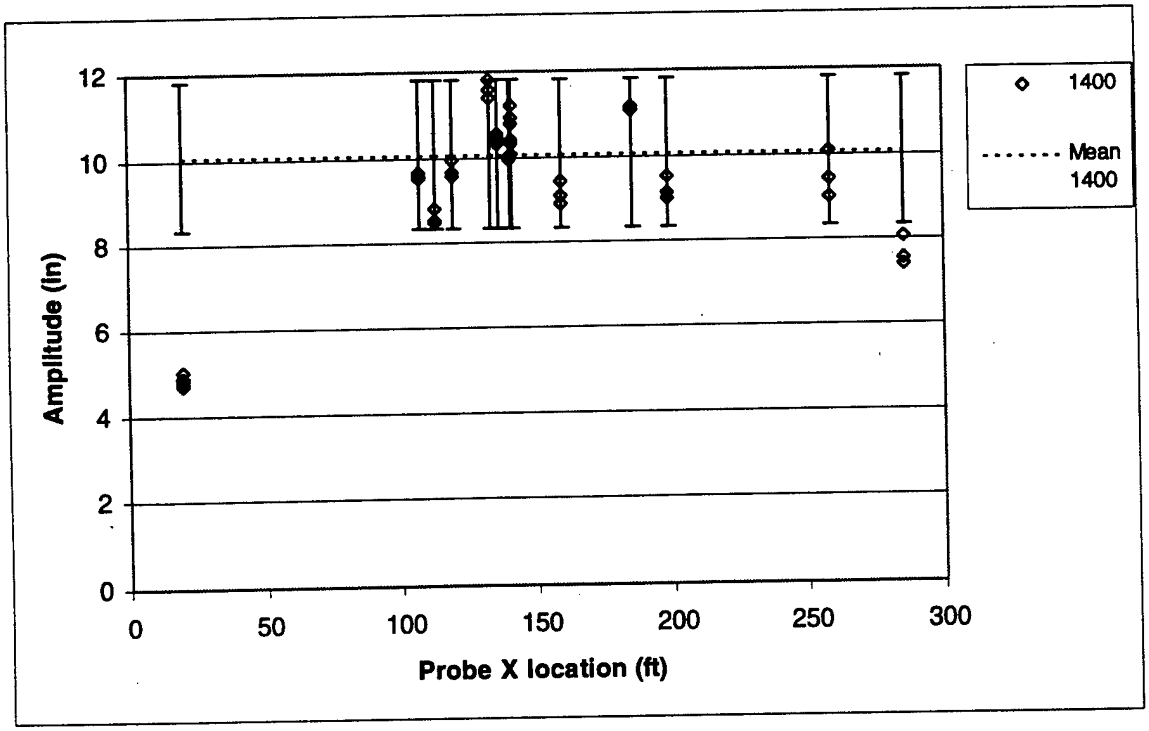

Figure 8. Wave amplitude by probe location and blower speed (rpm) at 2.58 seconds on 'A' bank.

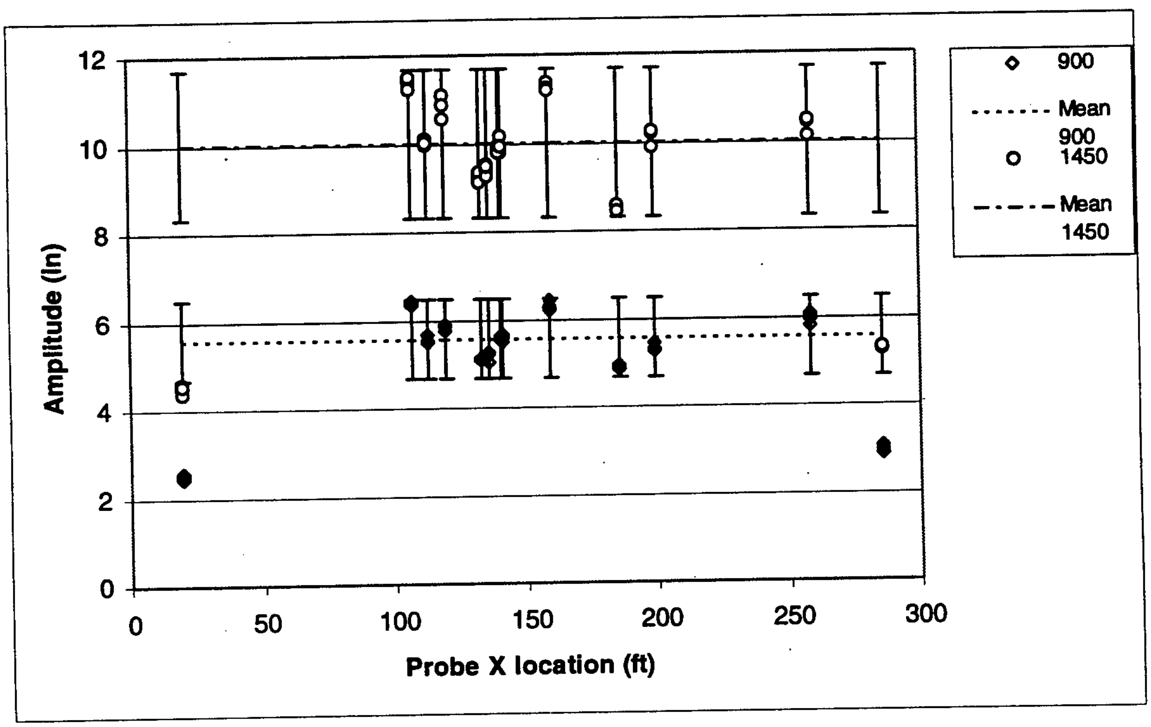

Figure 9. Wave amplitude by probe location and blower speed (rpm) at 3.1 seconds on 'A' bank.

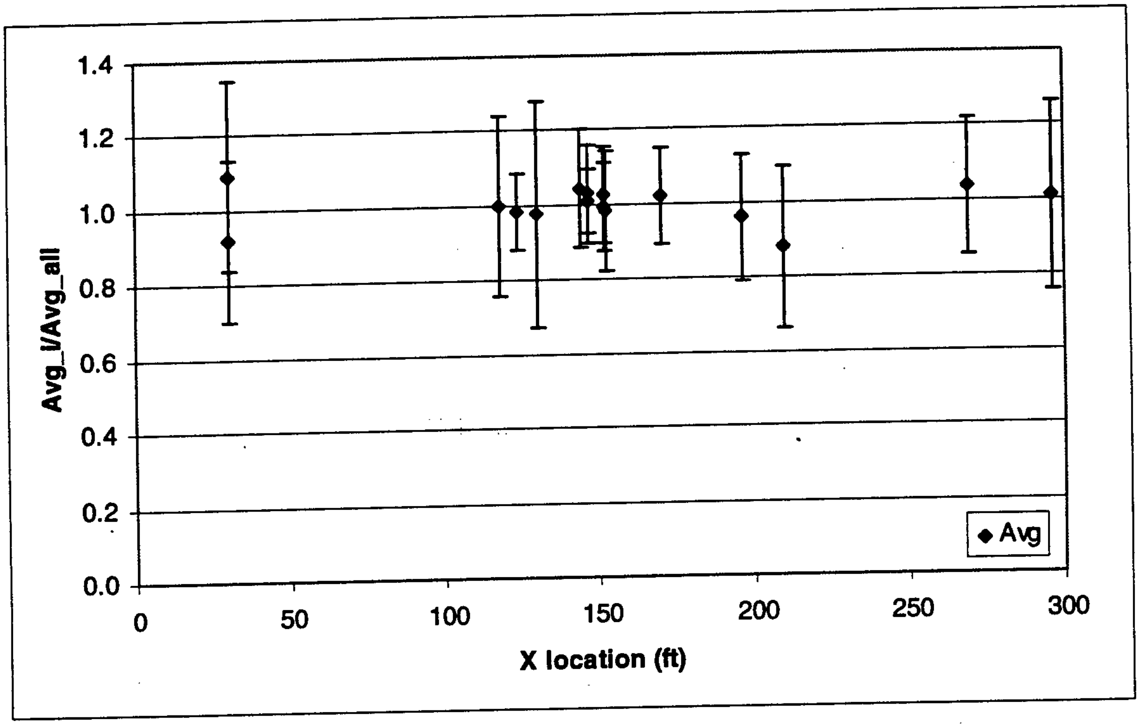

Figure 10. Normalized average wave amplitude averaged over all conditions for 'B' bank with 2σ error bars.

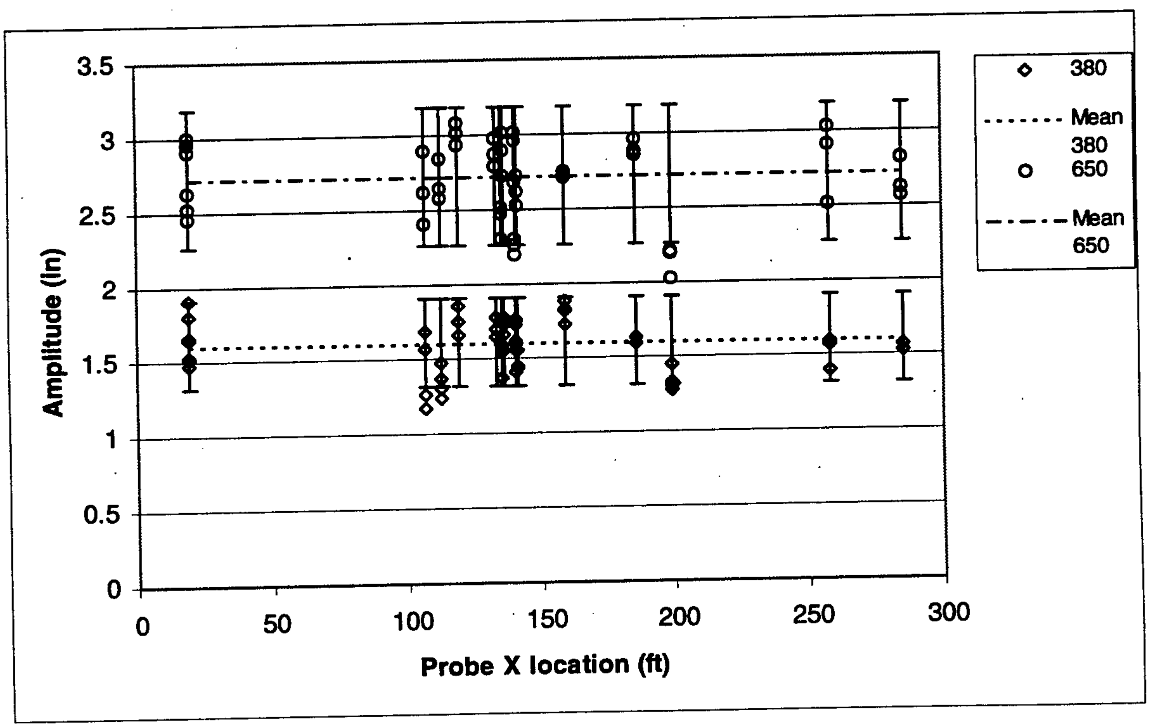

Figure 11. Wave amplitude by probe location and blower speed (rpm) at 1.29 seconds on 'B' bank.

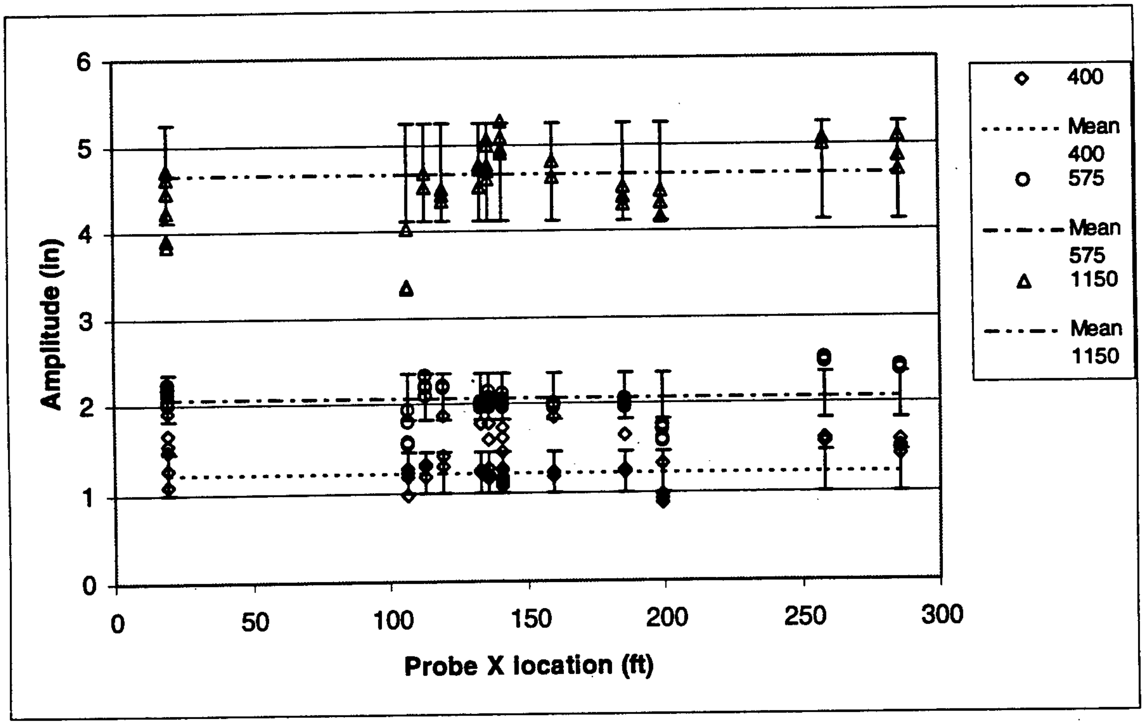

Figure 12. Wave amplitude by probe location and blower speed (rpm) at 1.55 seconds on 'B' bank.

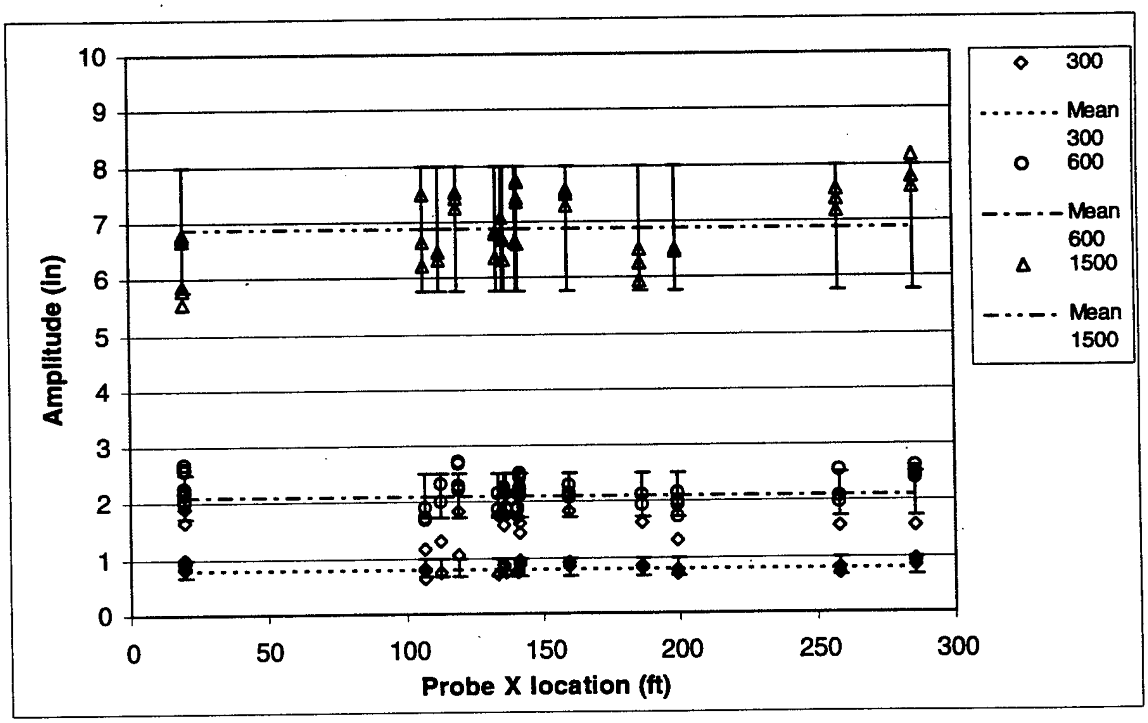

Figure 13. Wave amplitude by probe location and blower speed (rpm) at 1.81 seconds on 'B' bank.

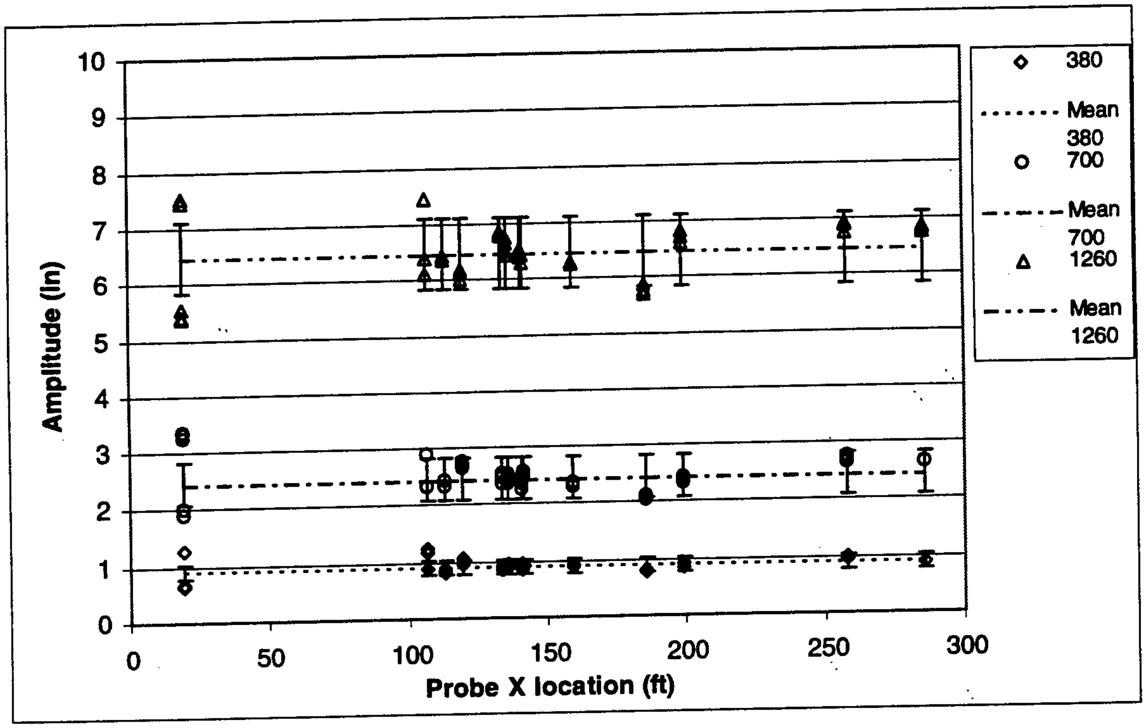

Figure 14. Wave amplitude by probe location and blower speed (rpm) at 2.06 seconds on 'B' bank.

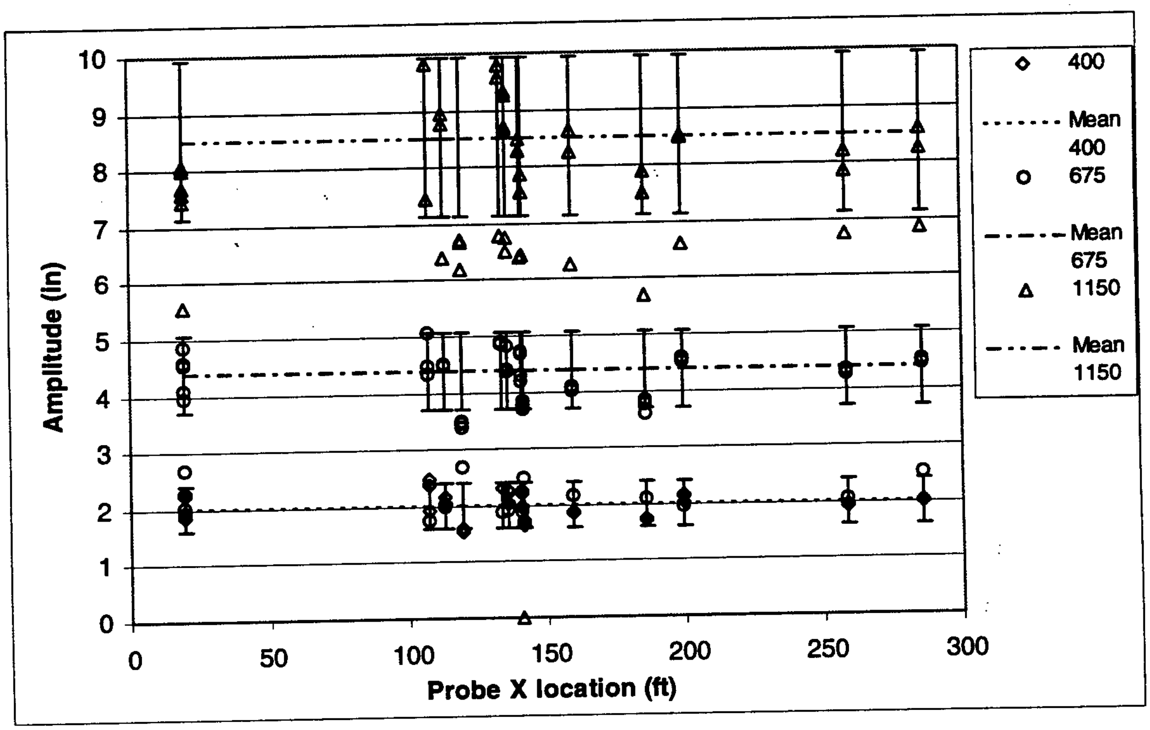

Figure 15. Wave amplitude by probe location and blower speed (rpm) at 2.32 seconds on 'B' bank.

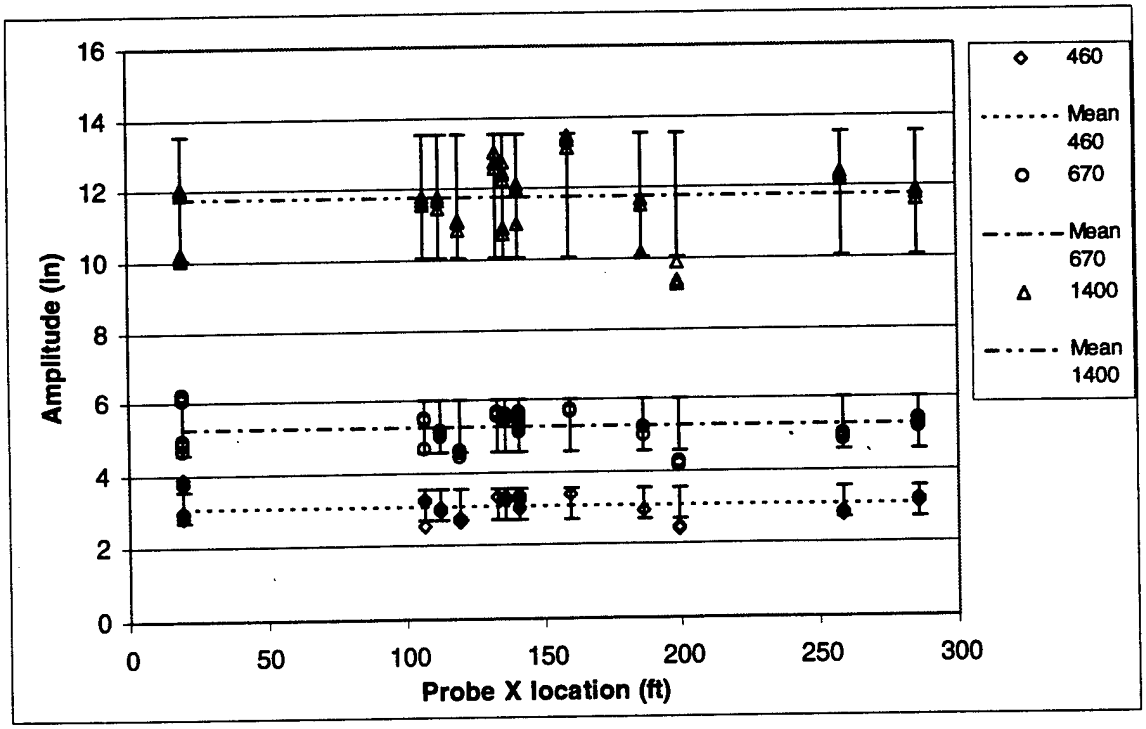

Figure 16. Wave amplitude by probe location and blower speed (rpm) at 2.58 seconds on 'B' bank.

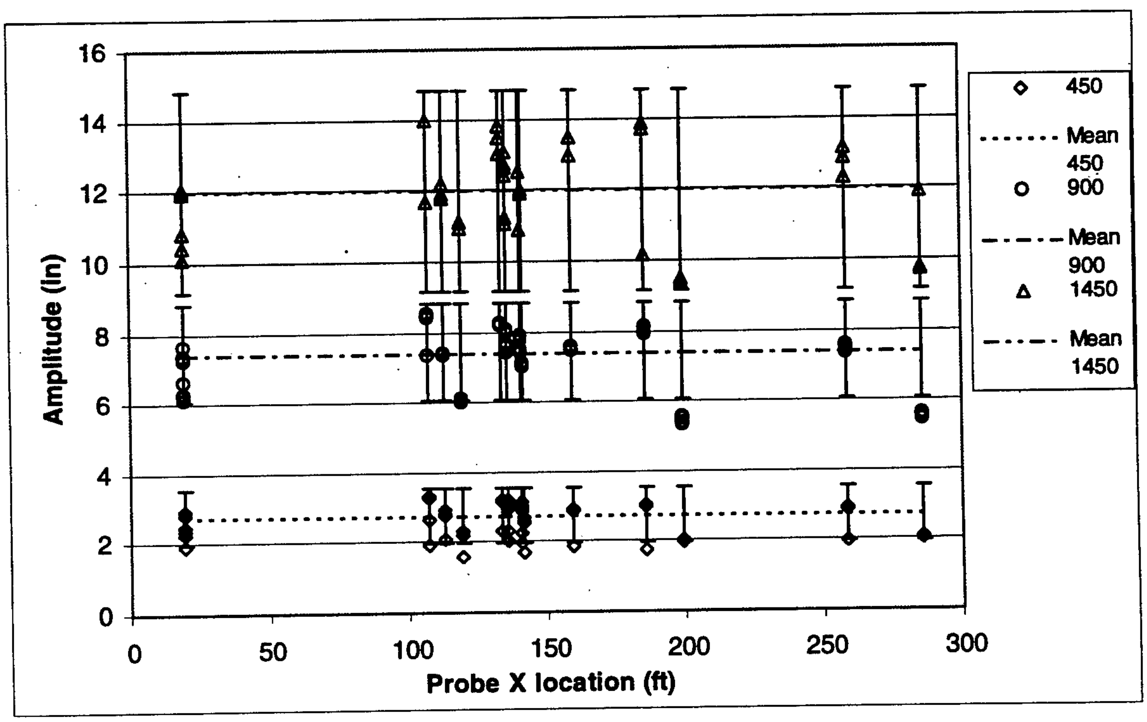

Figure 17. Wave amplitude by probe location and blower speed (rpm) at 3.1 seconds on 'B' bank.

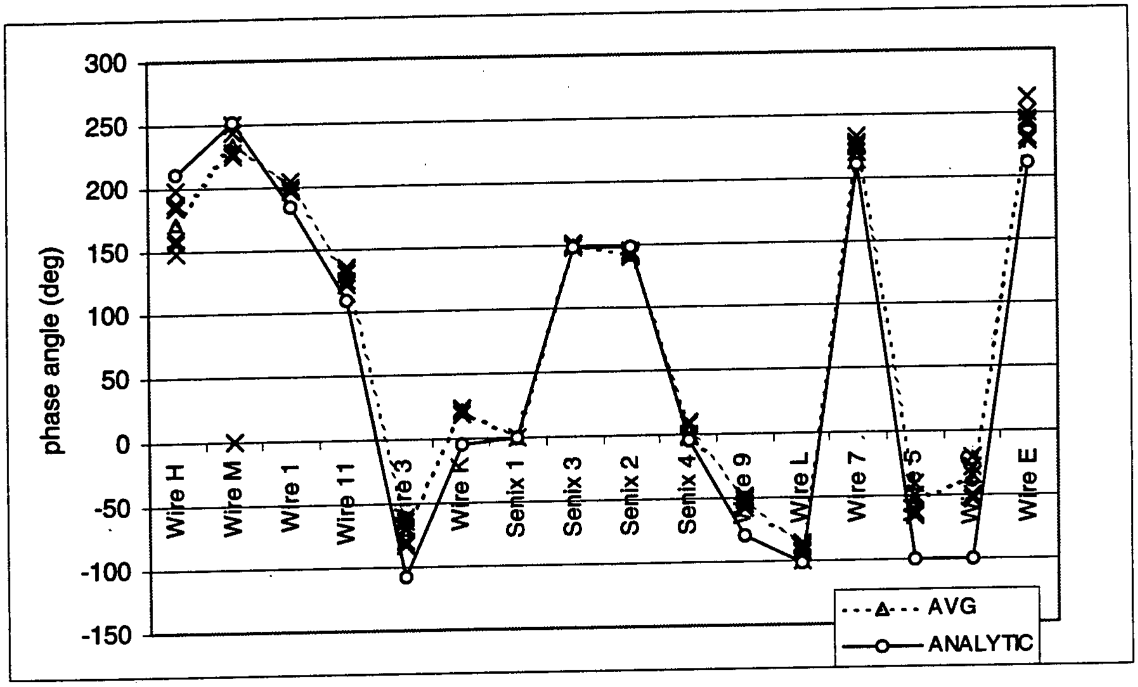

Figure 18. Wave phase angle by probe for 1.29 second period from 'A' bank.

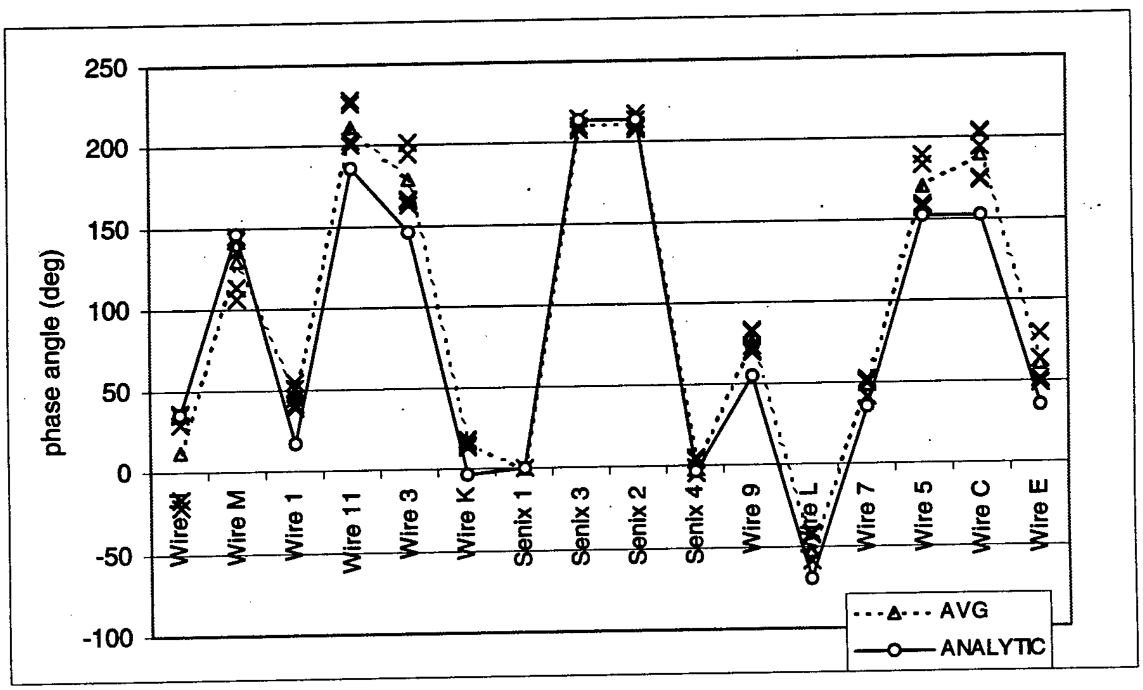

Figure 19. Wave phase angle by probe for 1.55 second period from 'A' bank.

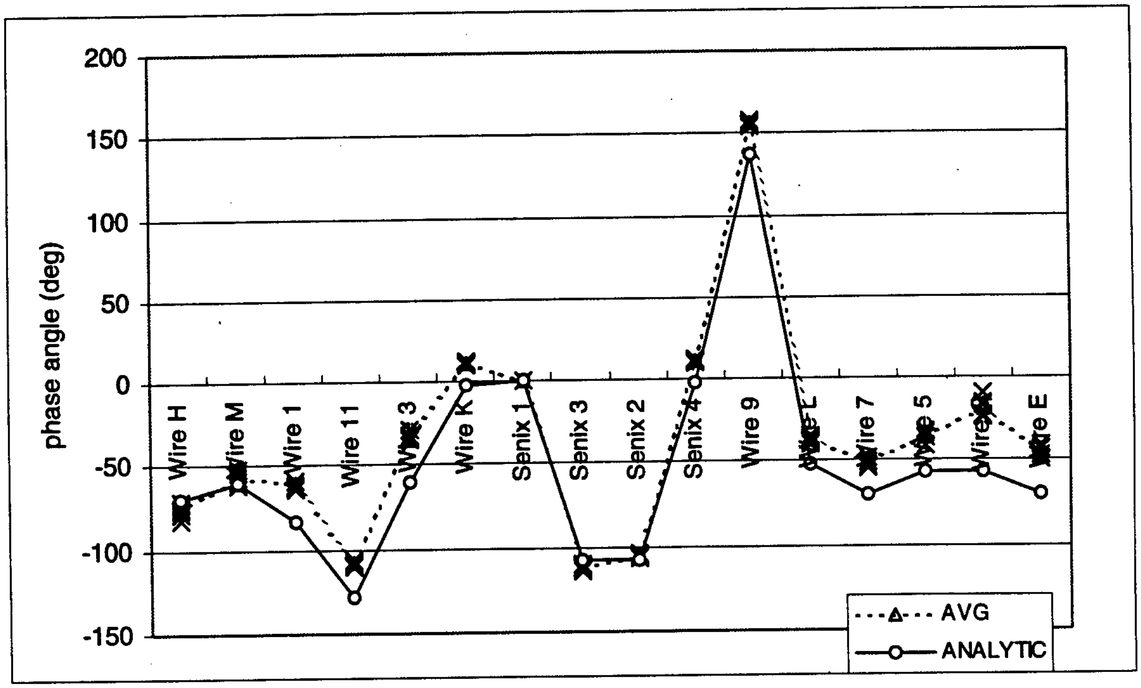

Figure 20. Wave phase angle by probe for 1.81 second period from 'A' bank.

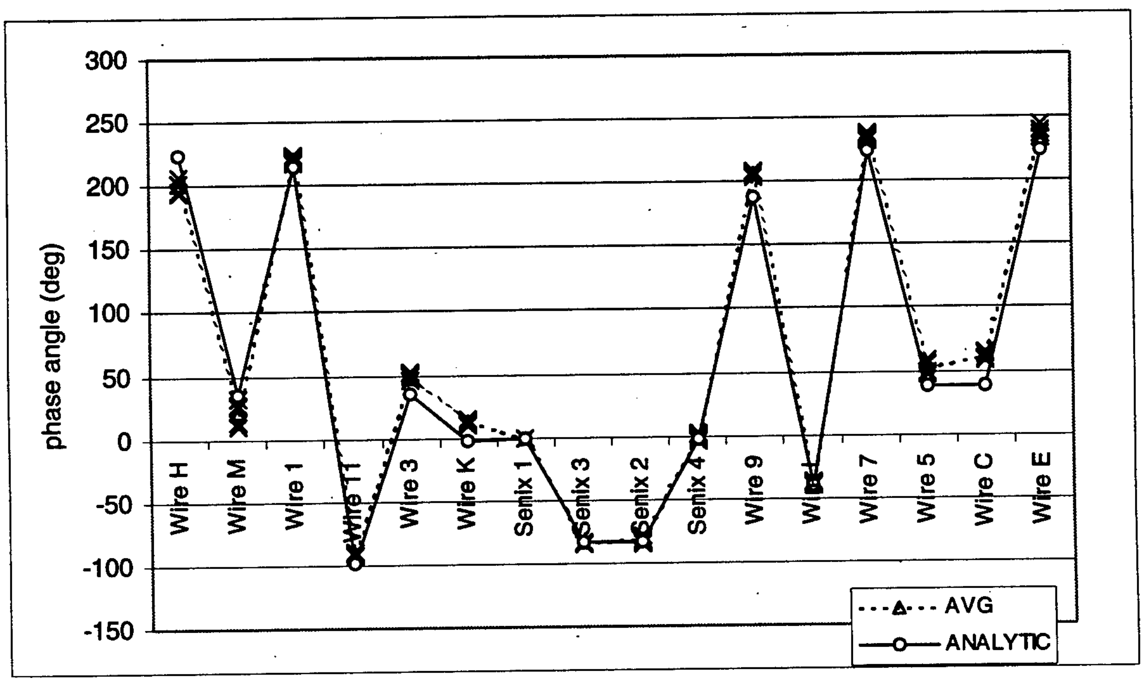

Figure 21. Wave phase angle by probe for 2.06 second period from 'A' bank.

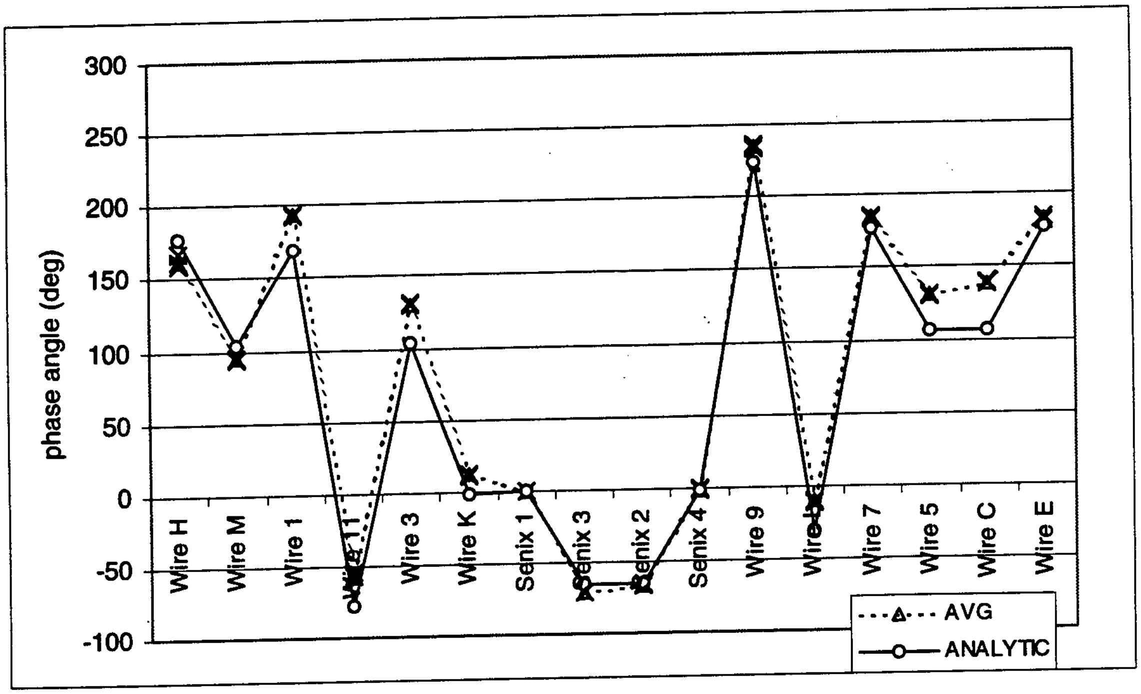

Figure 22. Wave phase angle by probe for 2.32 second period from 'A' bank.

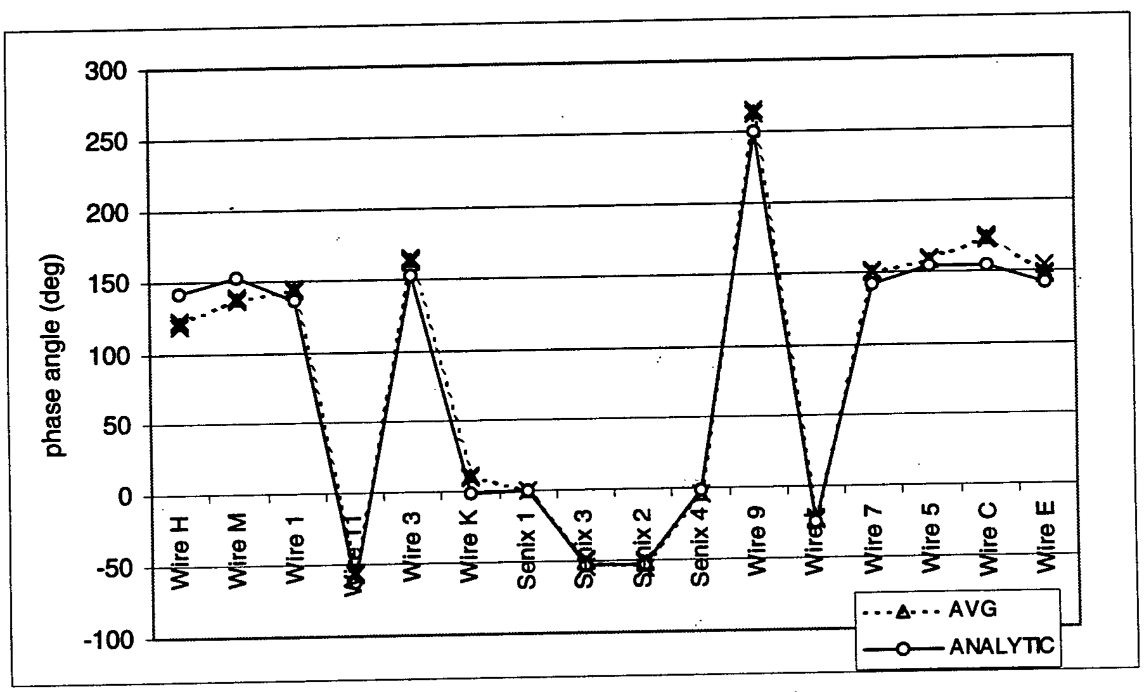

Figure 23. Wave phase angle by probe for 2.58 second period from 'A' bank.

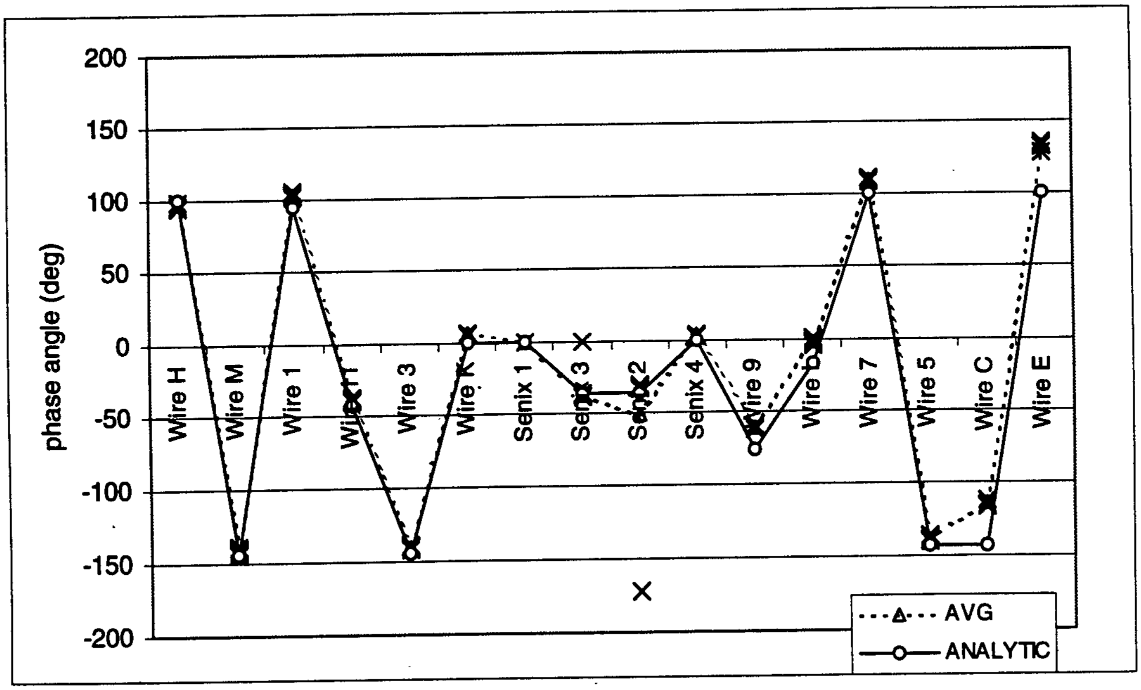

Figure 24. Wave phase angle by probe for 3.1 second period from 'A' bank.

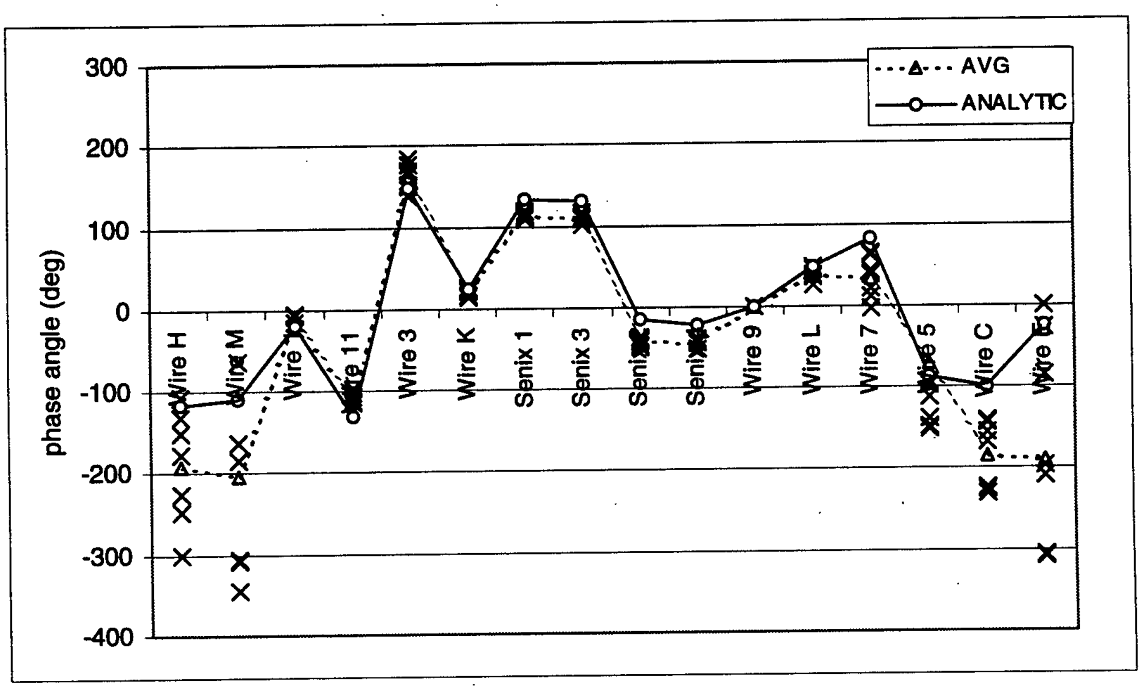

Figure 25. Wave phase angle by probe for 1.29 second period from 'B' bank.

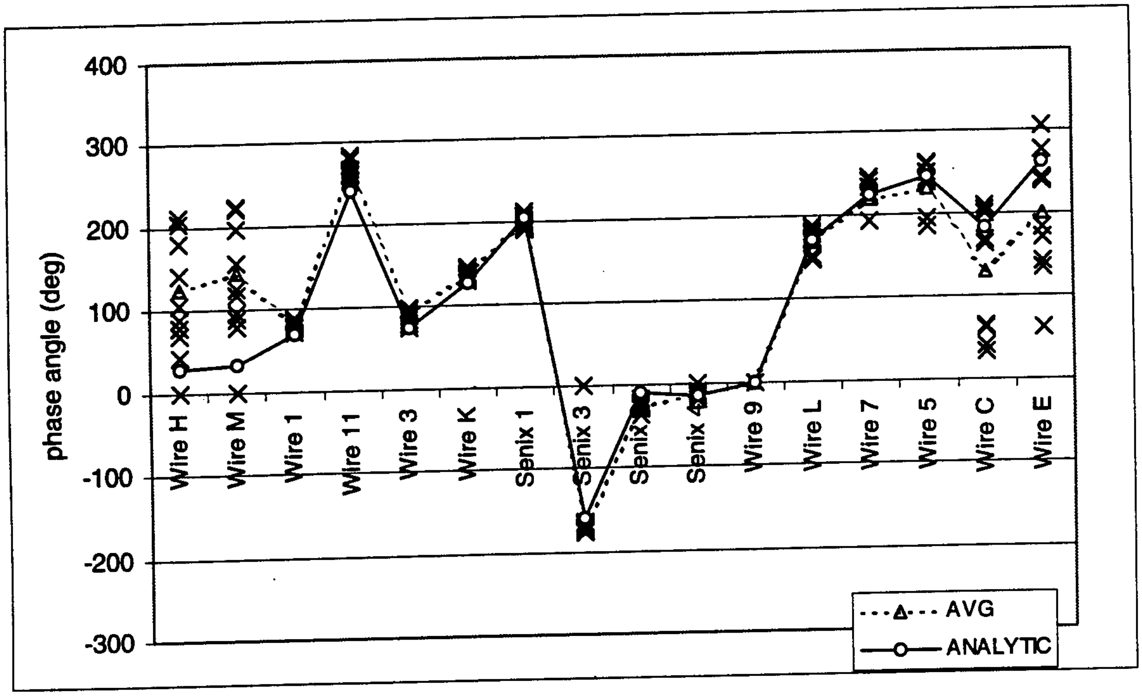

Figure 26. Wave phase angle by probe for 1.55 second period from 'B' bank.

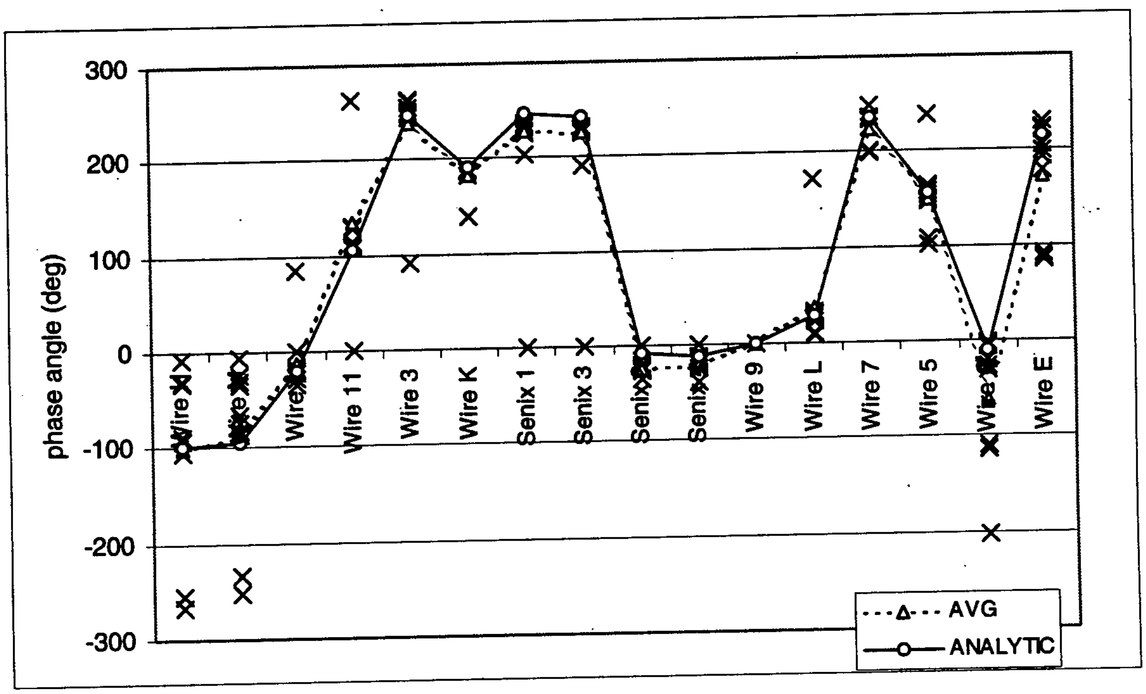

Figure 27. Wave phase angle by probe for 1.81 second period from 'B' bank.

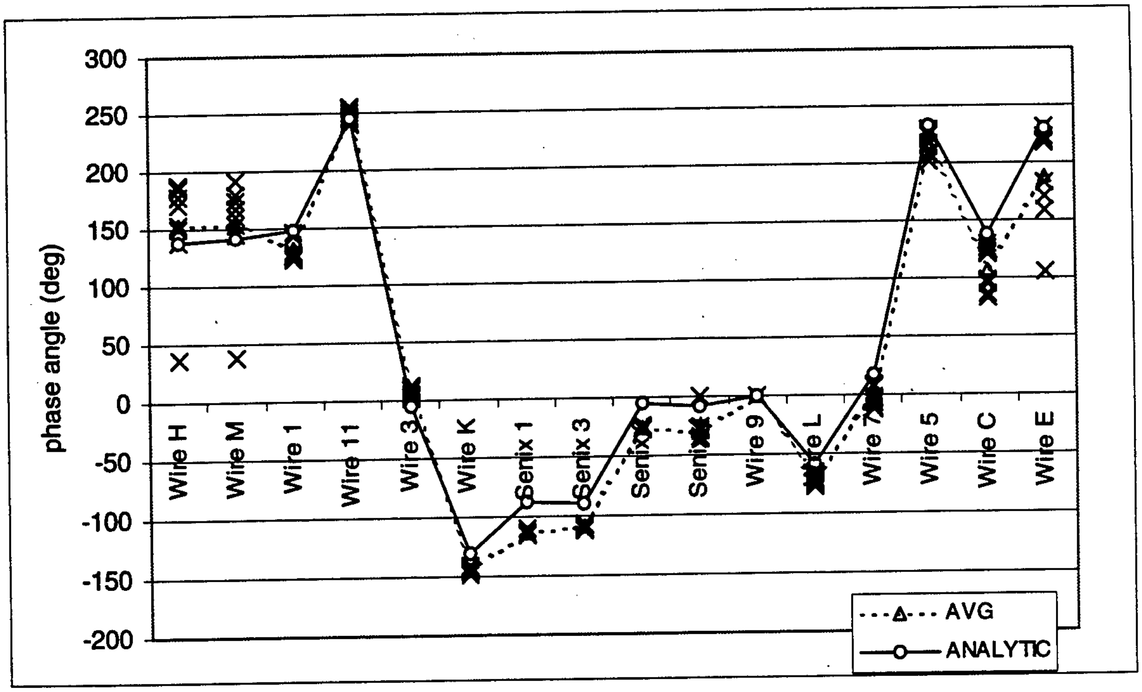

Figure 28. Wave phase angle by probe for 2.06 second period from 'B' bank.

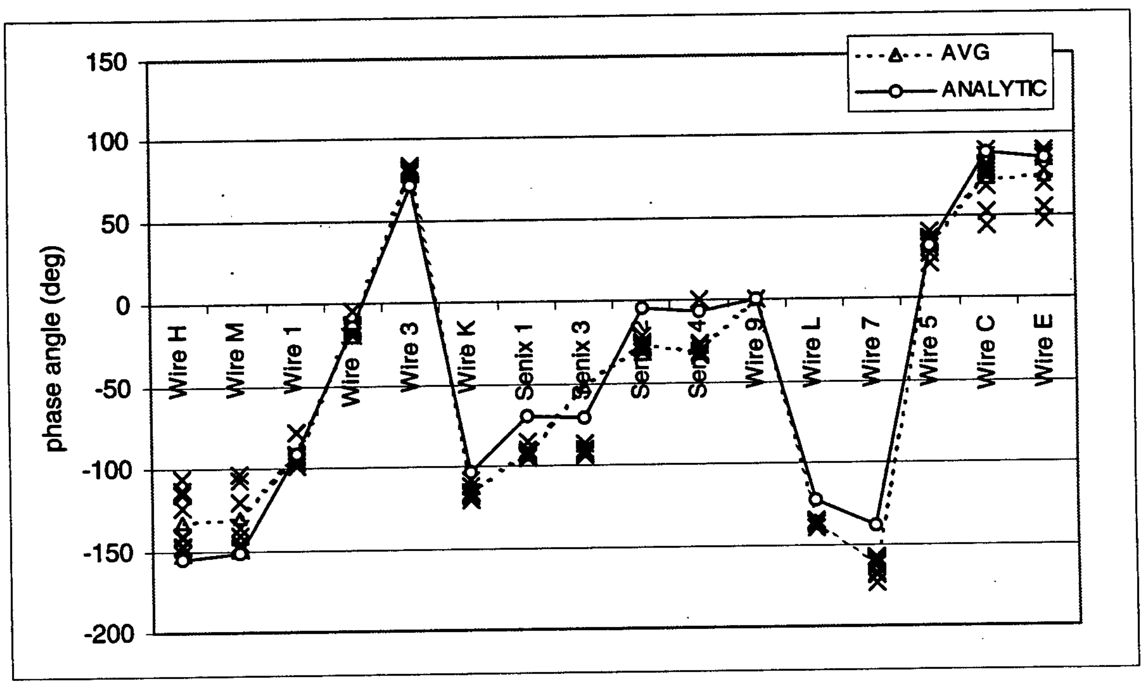

Figure 29. Wave phase angle by probe for 2.32 second period from 'B' bank.

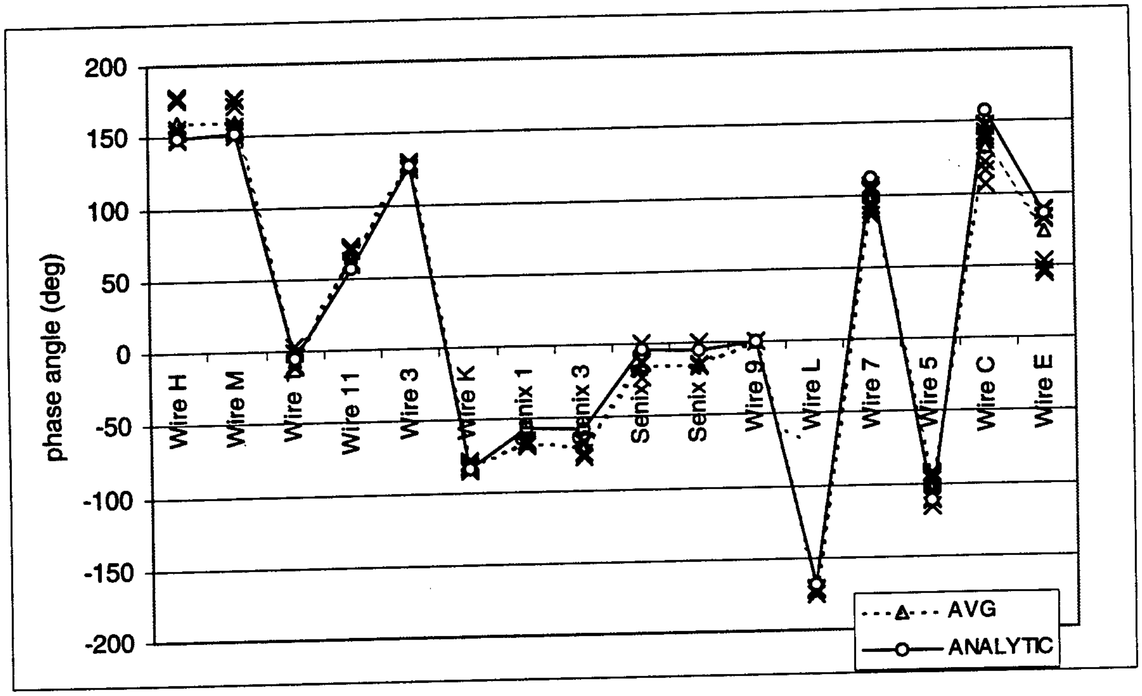

Figure 30. Wave phase angle by probe for 2.58 second period from 'B' bank.

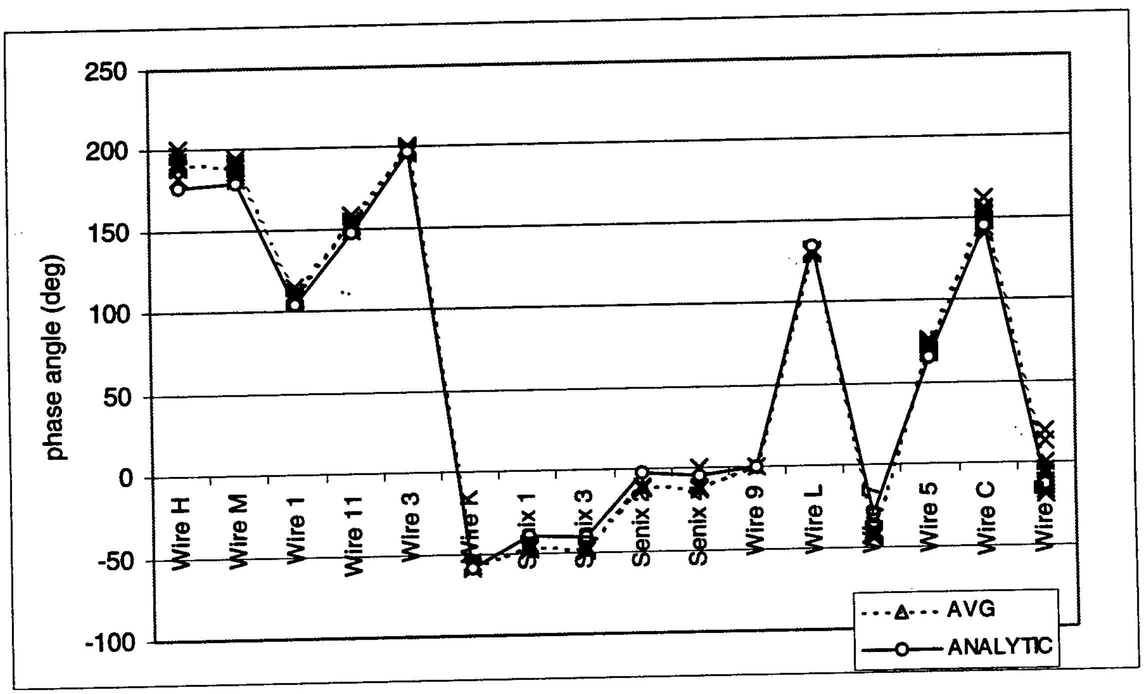

Figure 31. Wave phase angle by probe for 3.1 second period from 'B' bank.

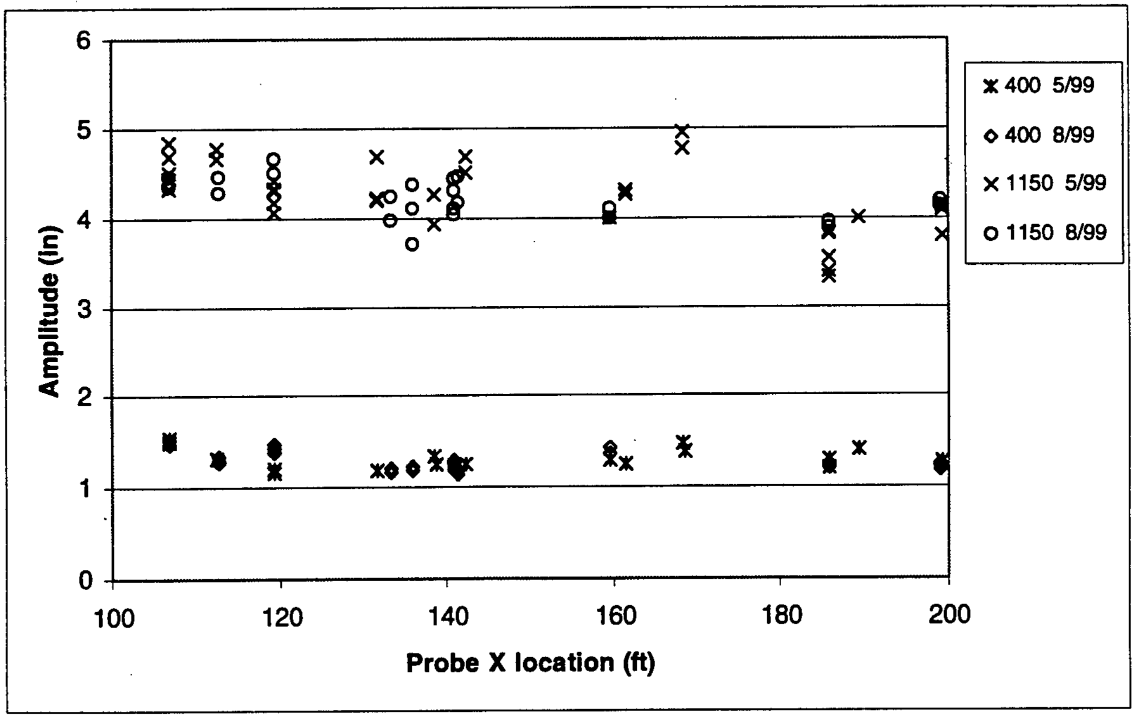

Figure 32. Comparison of wave survey wave amplitudes by X location for 1.55 second period and 'A' bank.

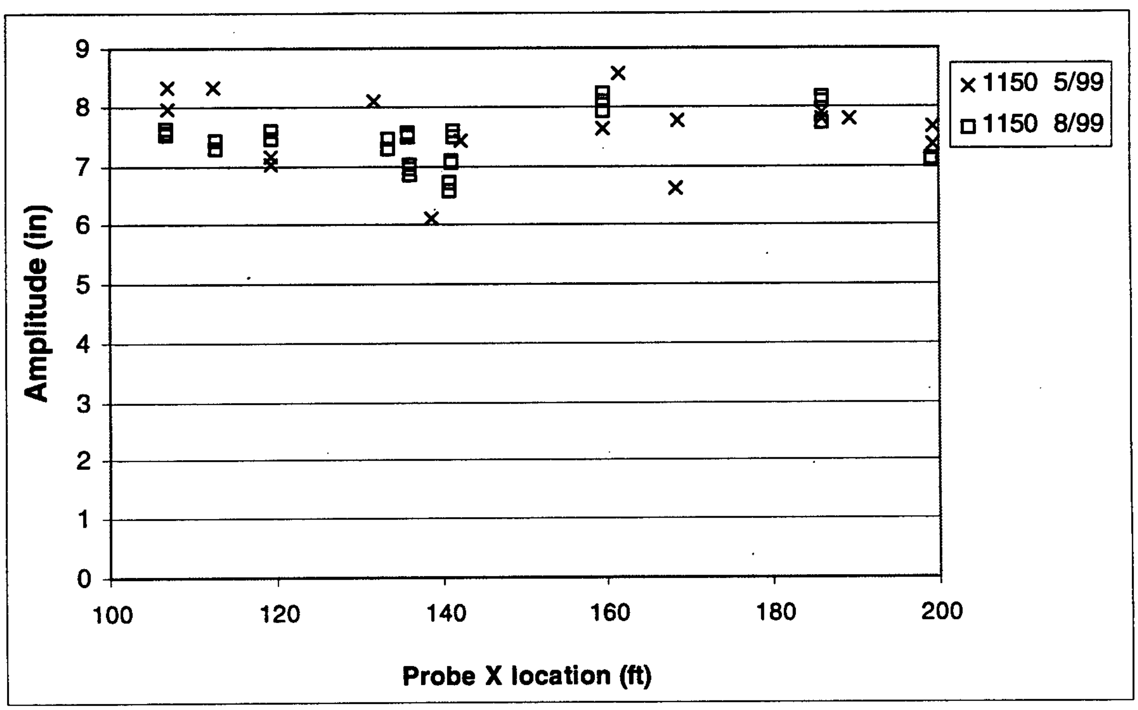

Figure 33. Comparison of wave survey wave amplitudes by X location for 2.32 second period and 'A' bank.

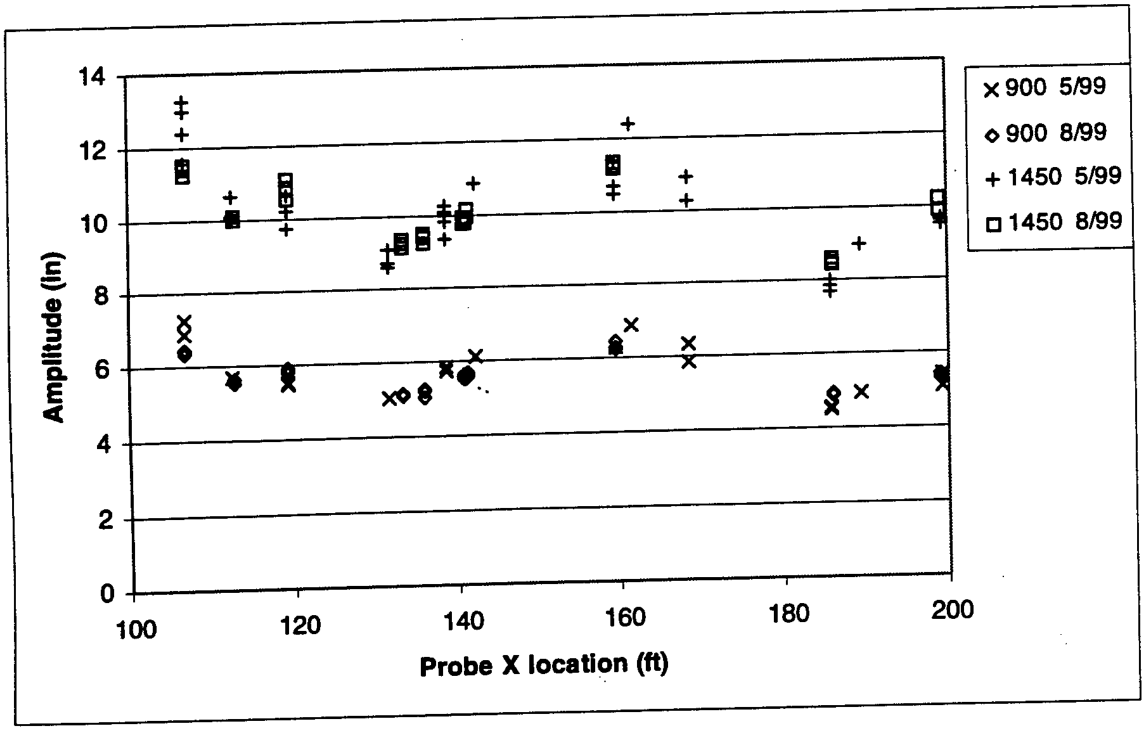

Figure 34. Comparison of wave survey wave amplitudes by X location for 3.1 second period and 'A' bank.

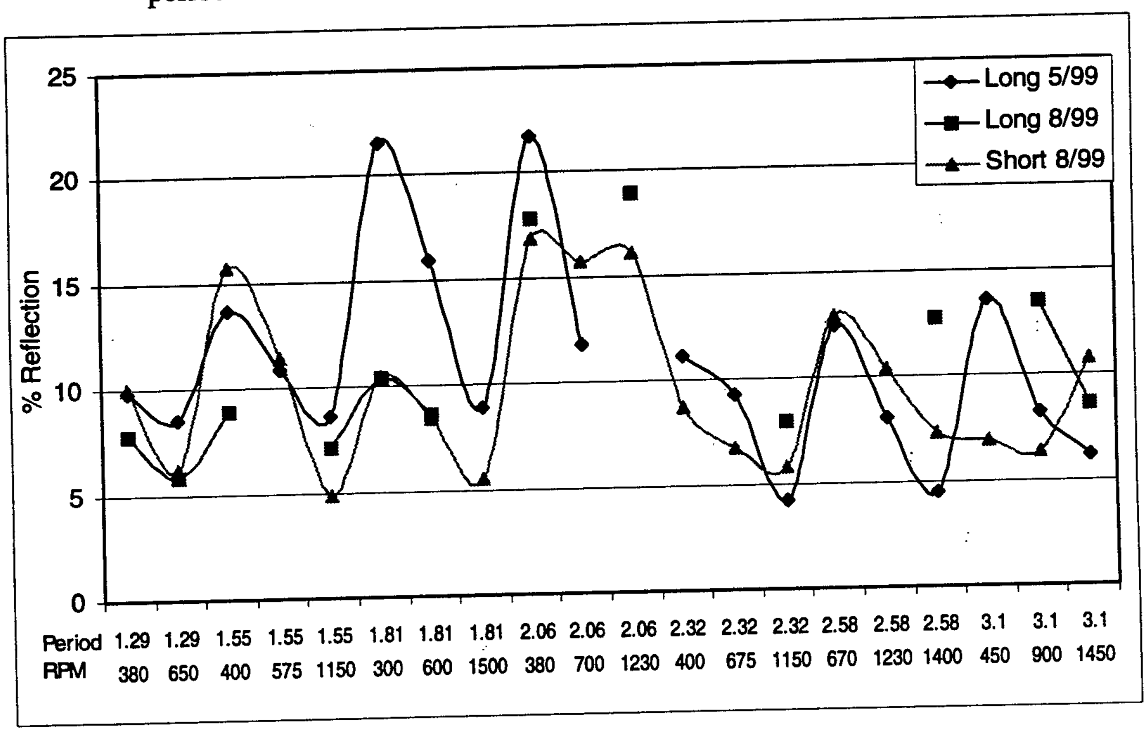

Figure 35. Beach reflection as percentage of incident wave for both wave surveys and 'A' and 'B' wavemaker banks for periods and blower speeds tested.

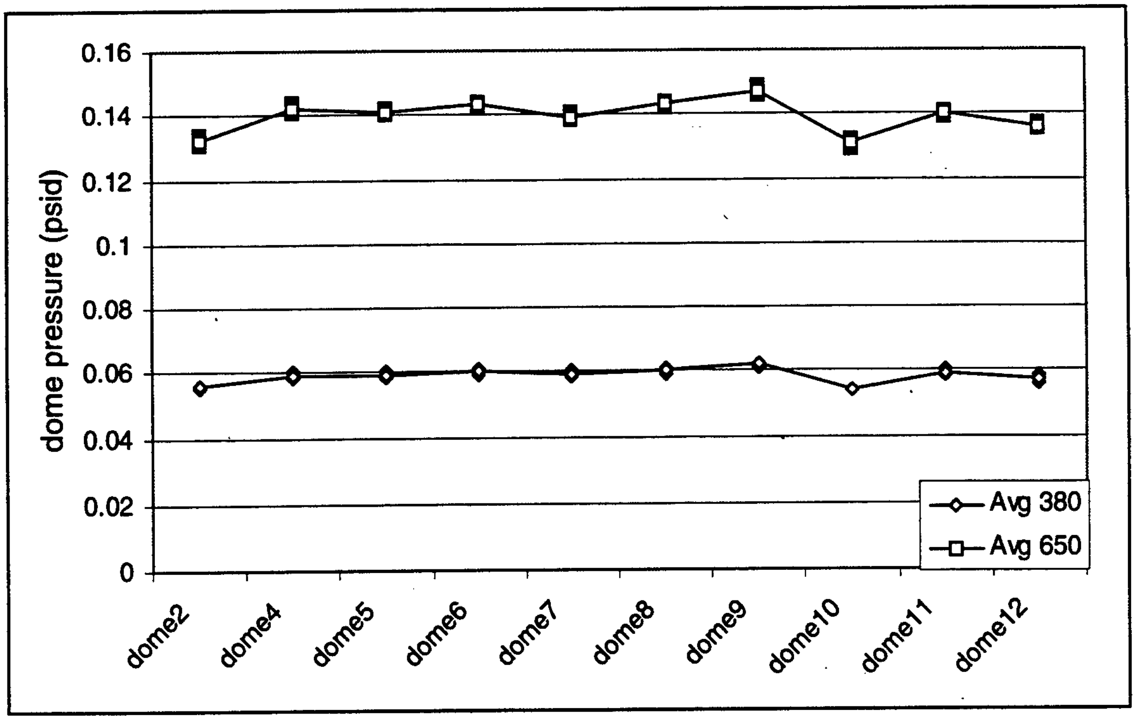

Figure 36. 'A' bank dome pressure for 1.29 second period at various blower speeds (rpm).

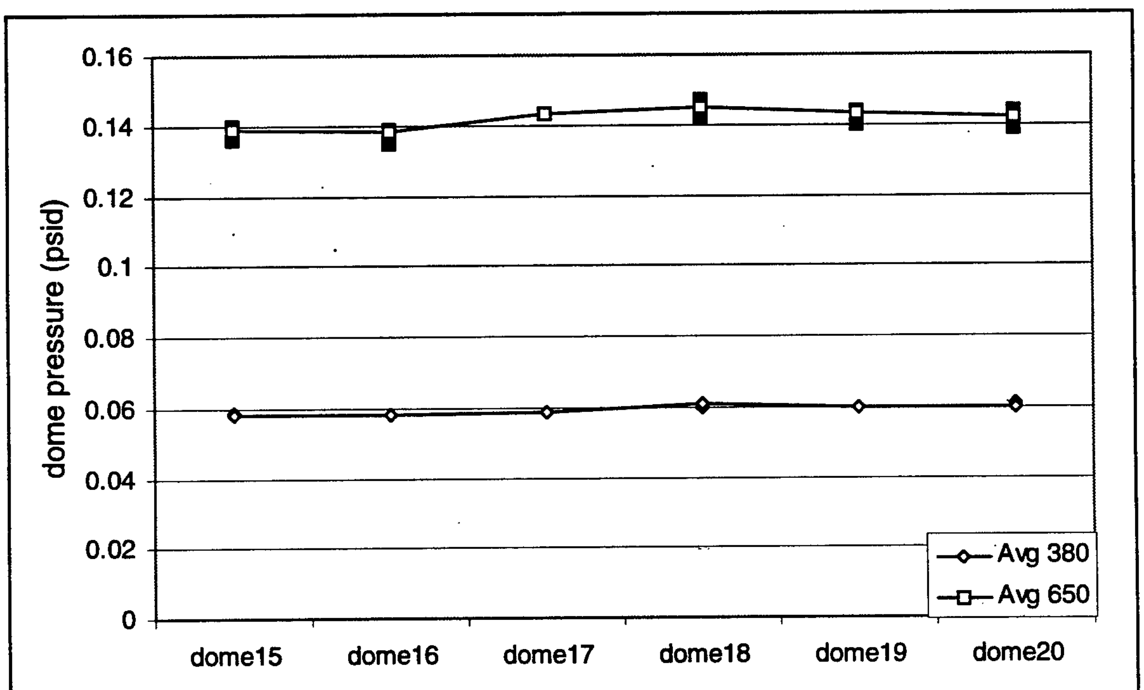

Figure 37. 'B' bank dome pressure for 1.29 second period at various blower speeds (rpm).

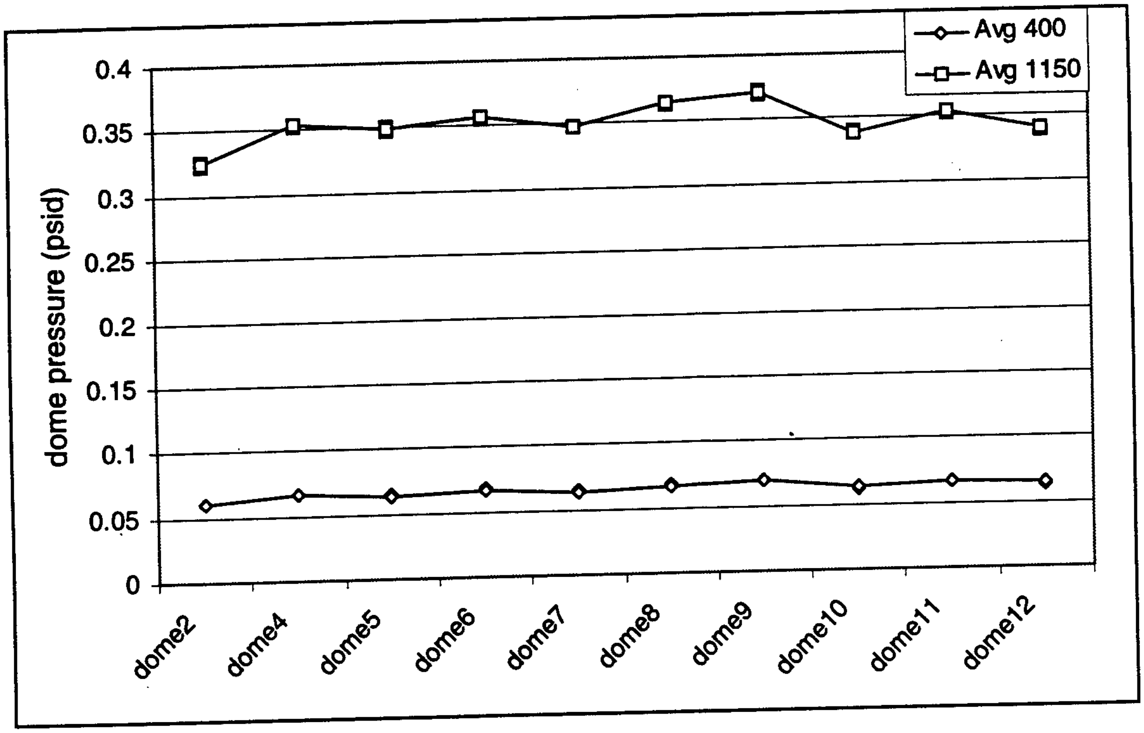

Figure 38. 'A' bank dome pressure for 1.55 second period at various blower speeds (rpm).

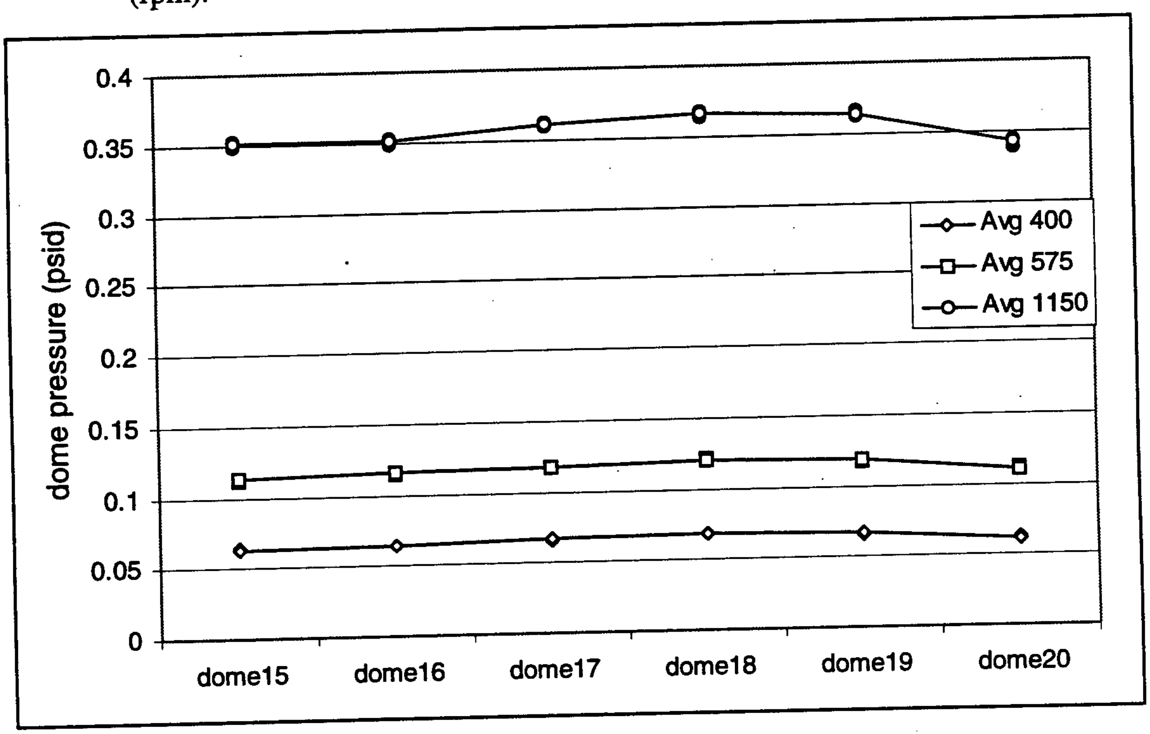

Figure 39. 'B' bank dome pressure for 1.55 second period at various blower speeds (rpm).

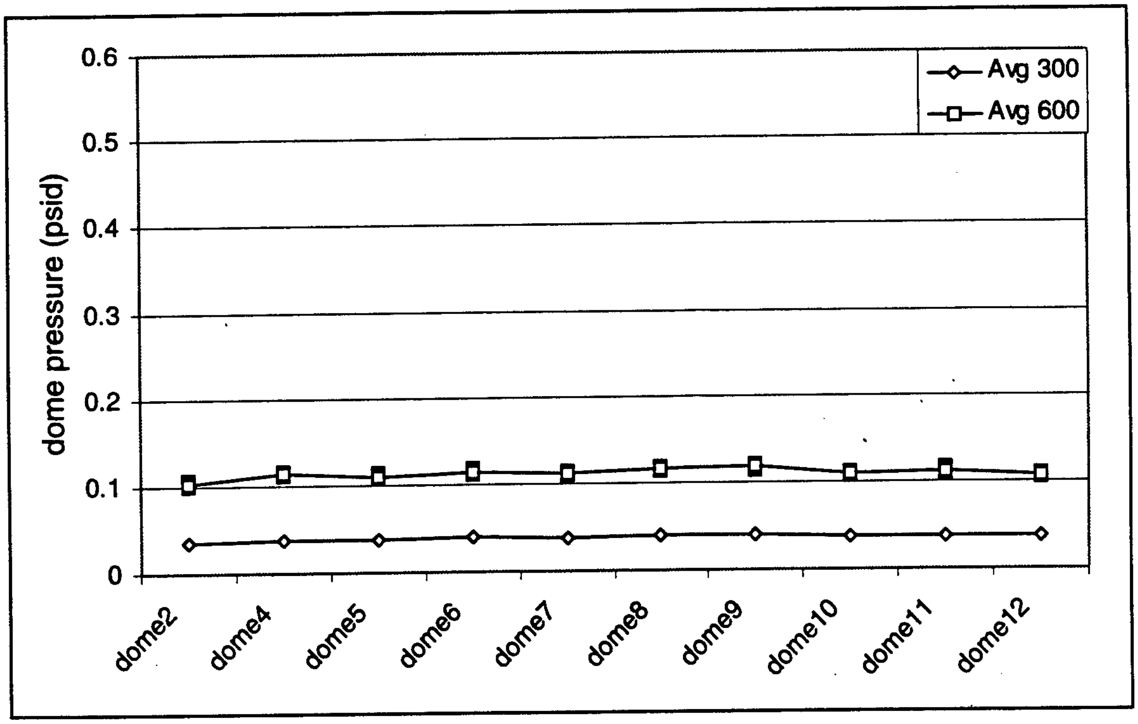

Figure 40. 'A' bank dome pressure for 1.81 second period at various blower speeds (rpm).

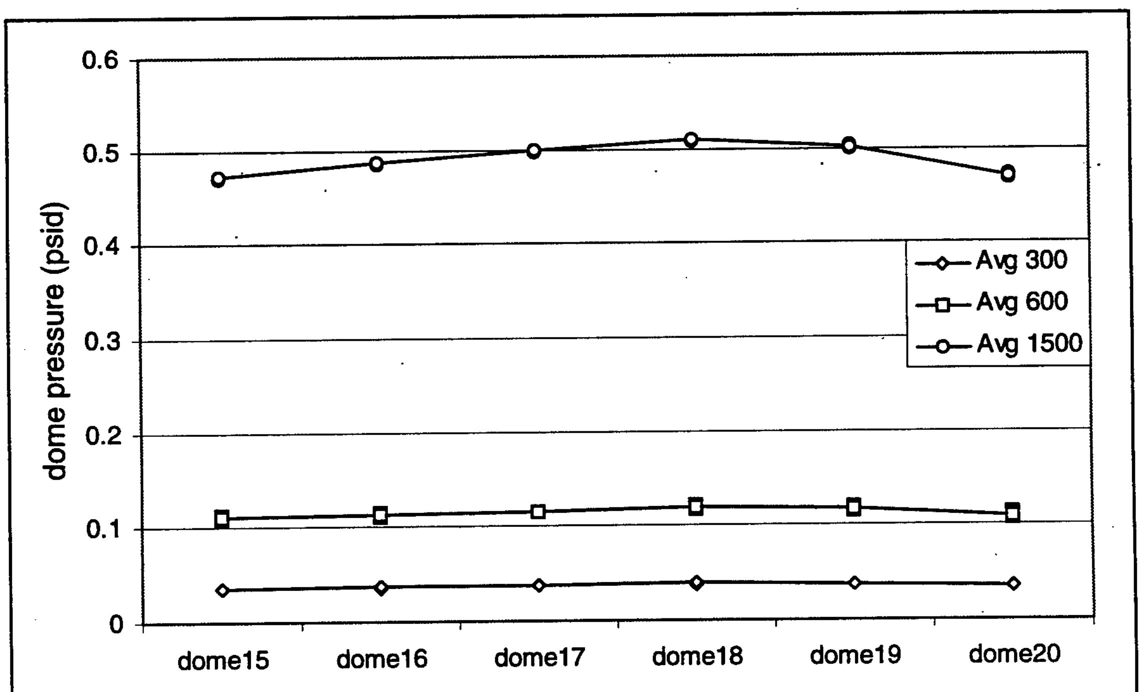

Figure 41. 'B' bank dome pressure for 1.81 second period at various blower speeds (rpm).

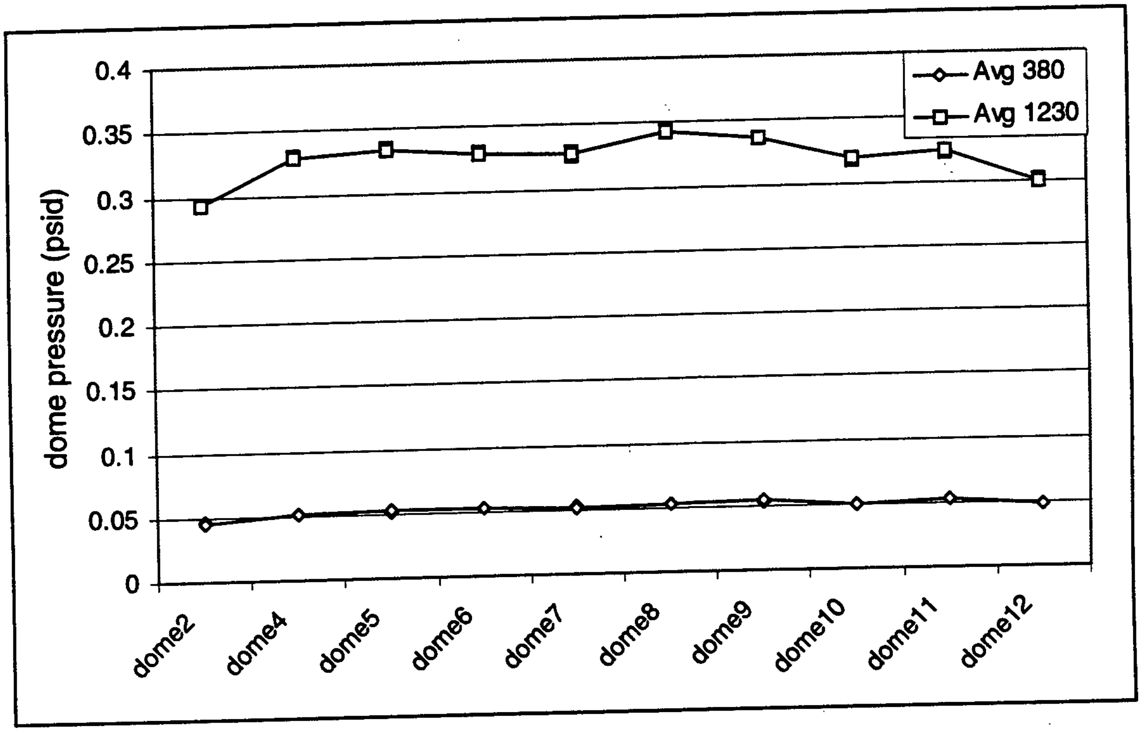

Figure 42. 'A' bank dome pressure for 2.06 second period at various blower speeds (rpm).

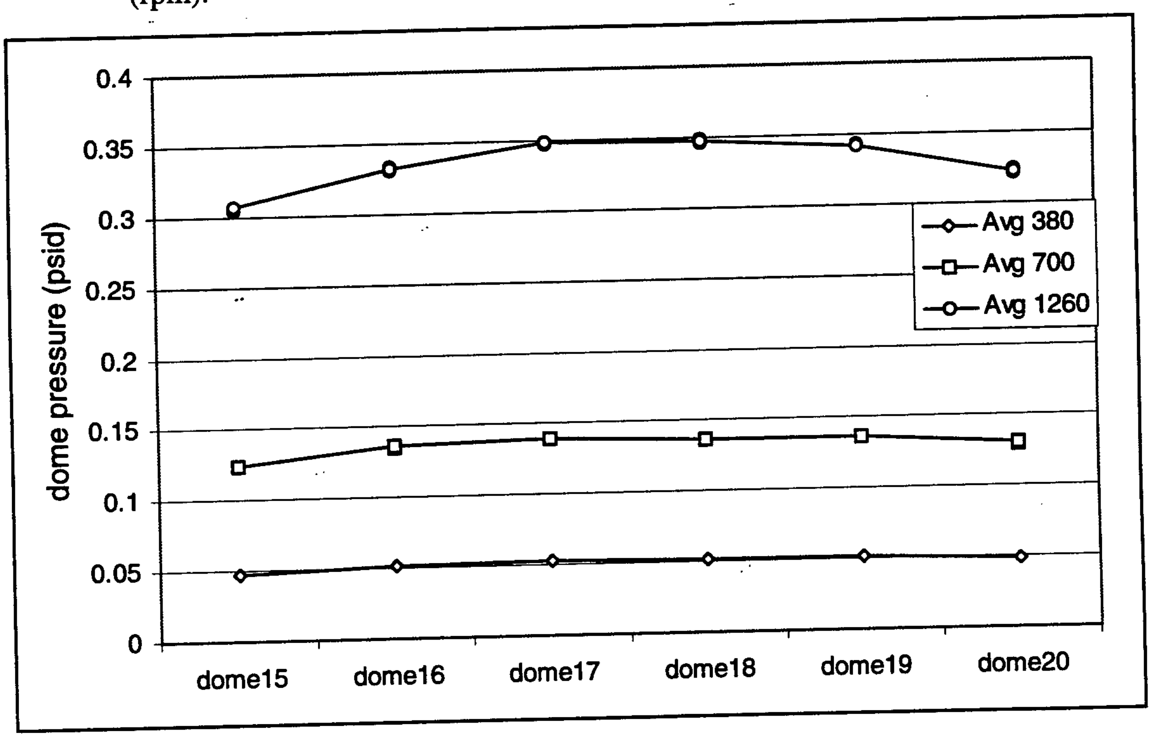

Figure 43. 'B' bank dome pressure for 2.06 second period at various blower speeds (rpm).

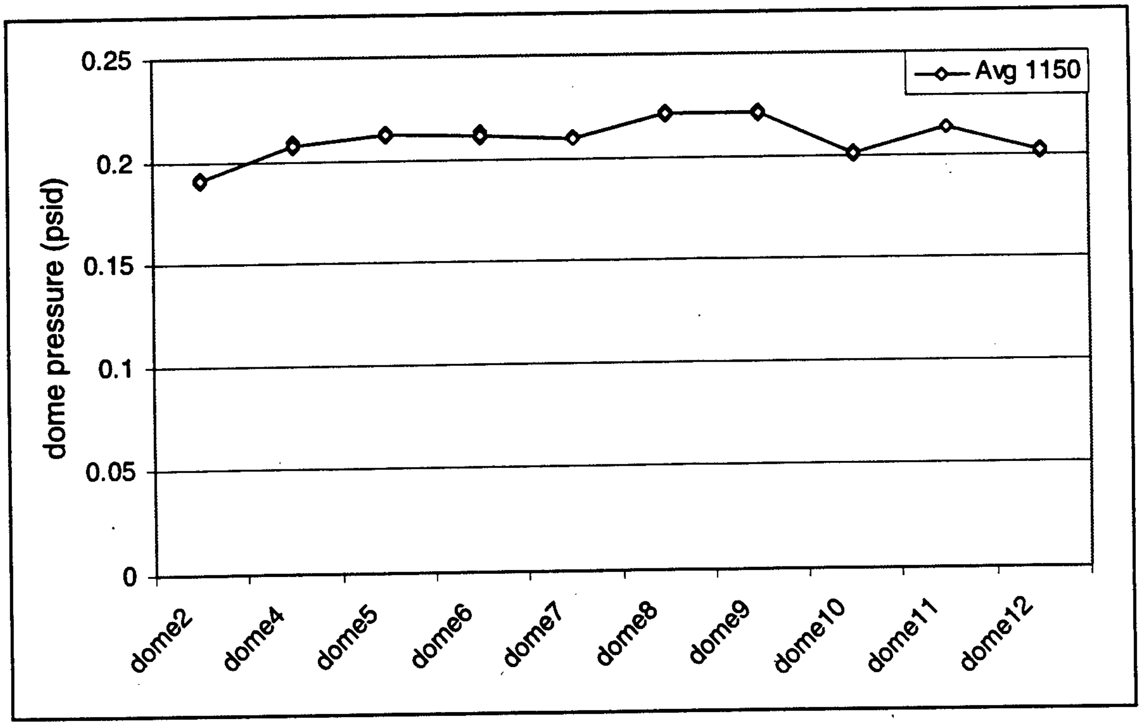

Figure 44. 'A' bank dome pressure for 2.32 second period at various blower speeds (rpm).

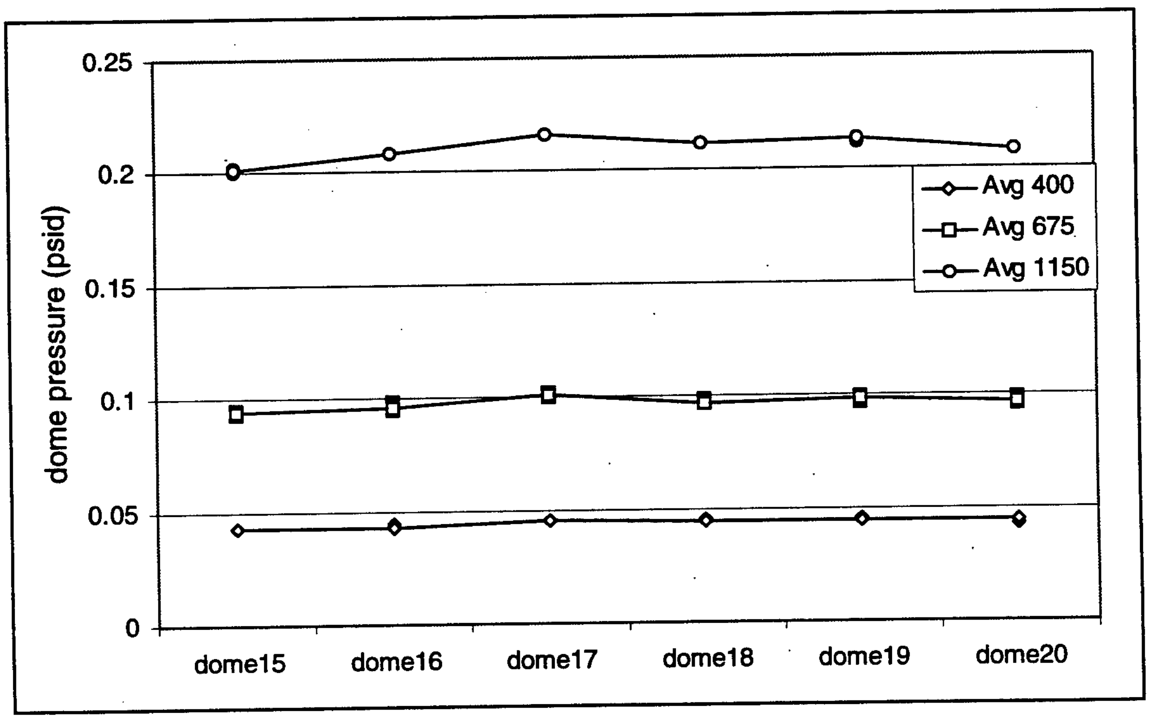

Figure 45. 'B' bank dome pressure for 2.32 second period at various blower speeds (rpm).

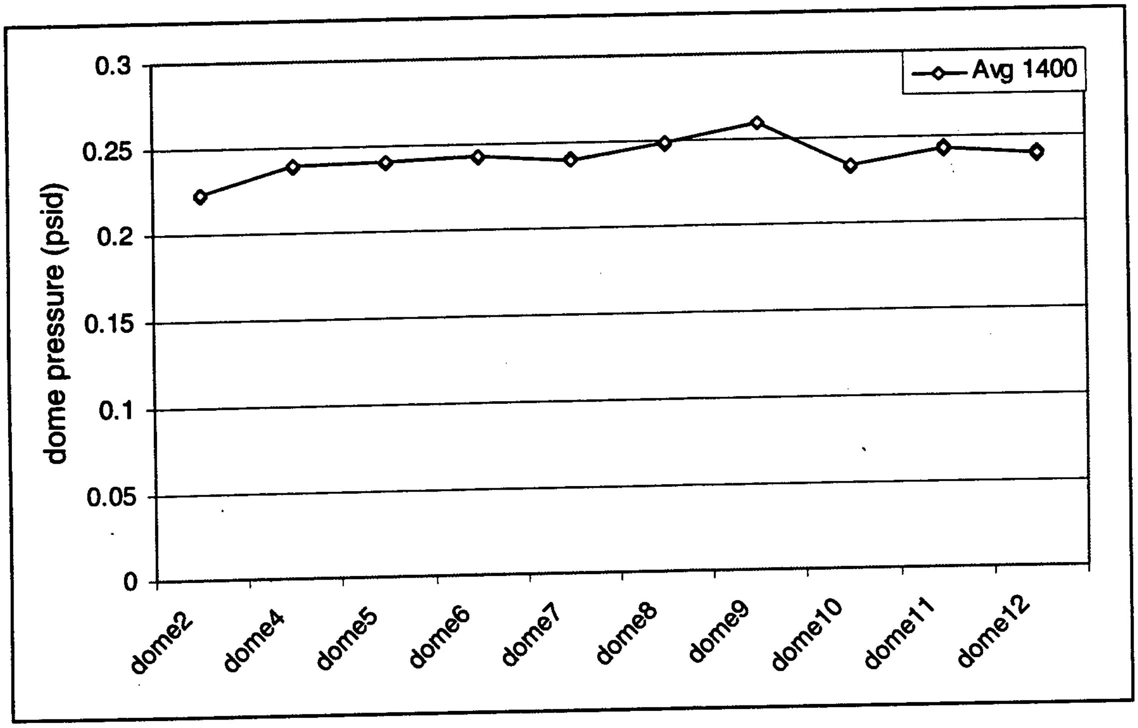

Figure 46. 'A' bank dome pressure for 2.58 second period at various blower speeds (rpm).

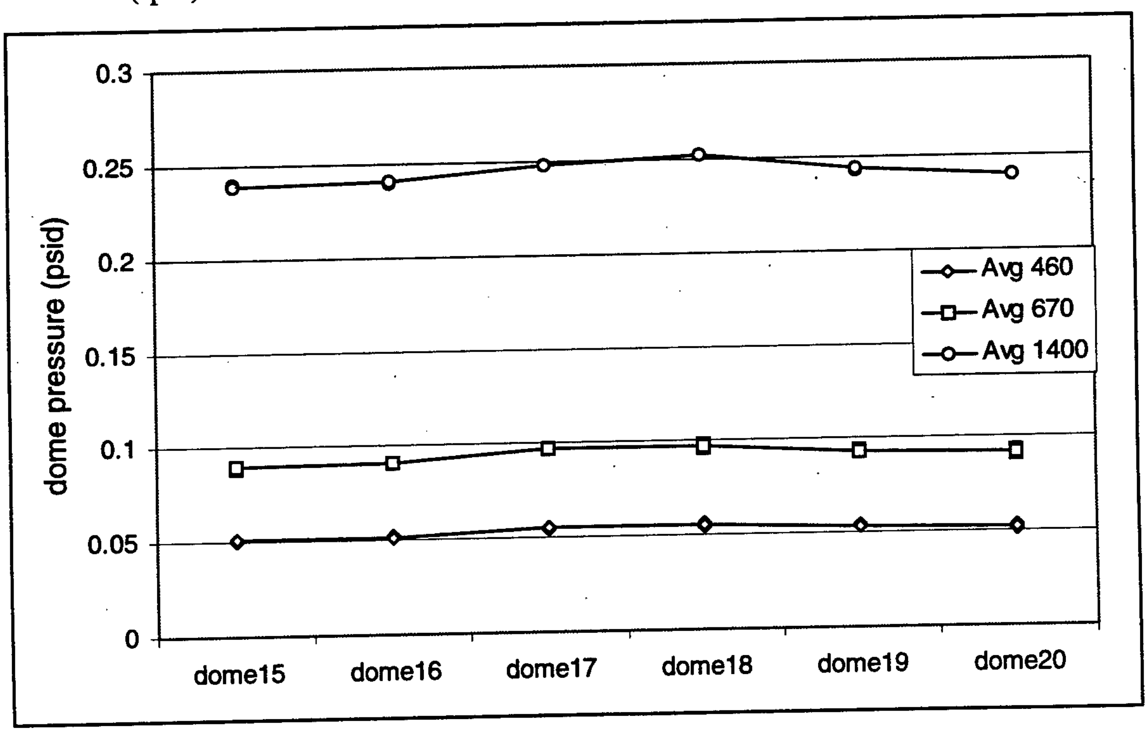

Figure 47. 'B' bank dome pressure for 2.58 second period at various blower speeds (rpm).

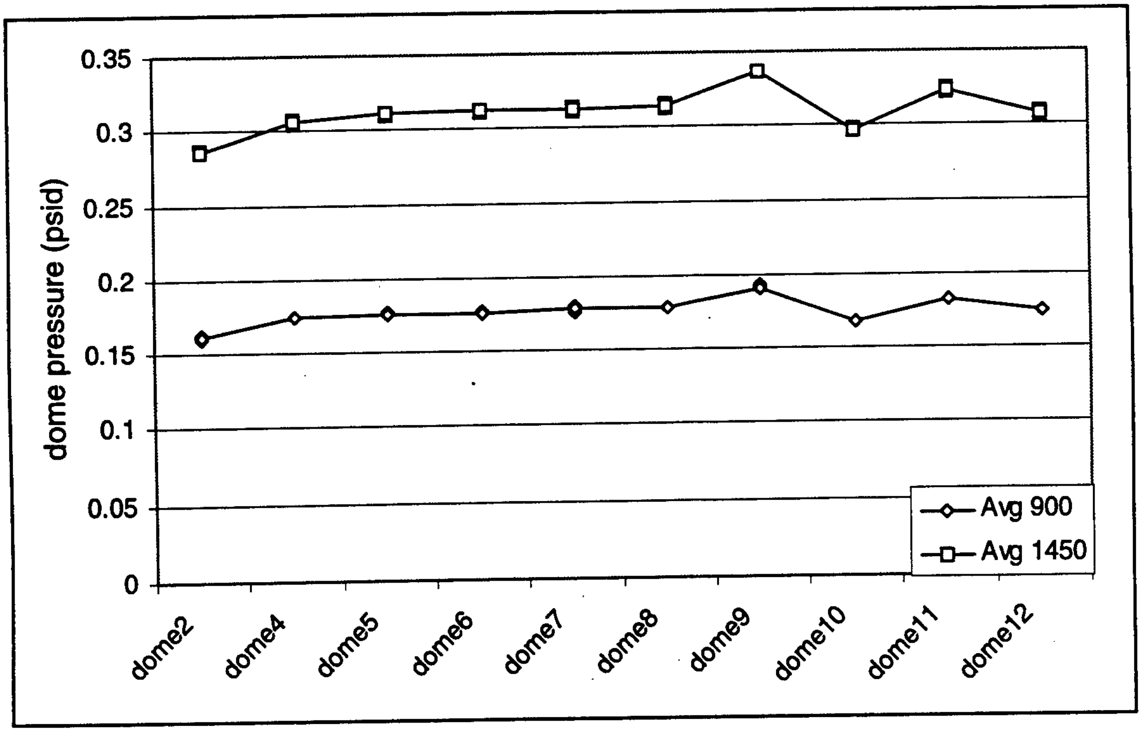

Figure 48. 'A' bank dome pressure for 3.1 second period at various blower speeds (rpm).

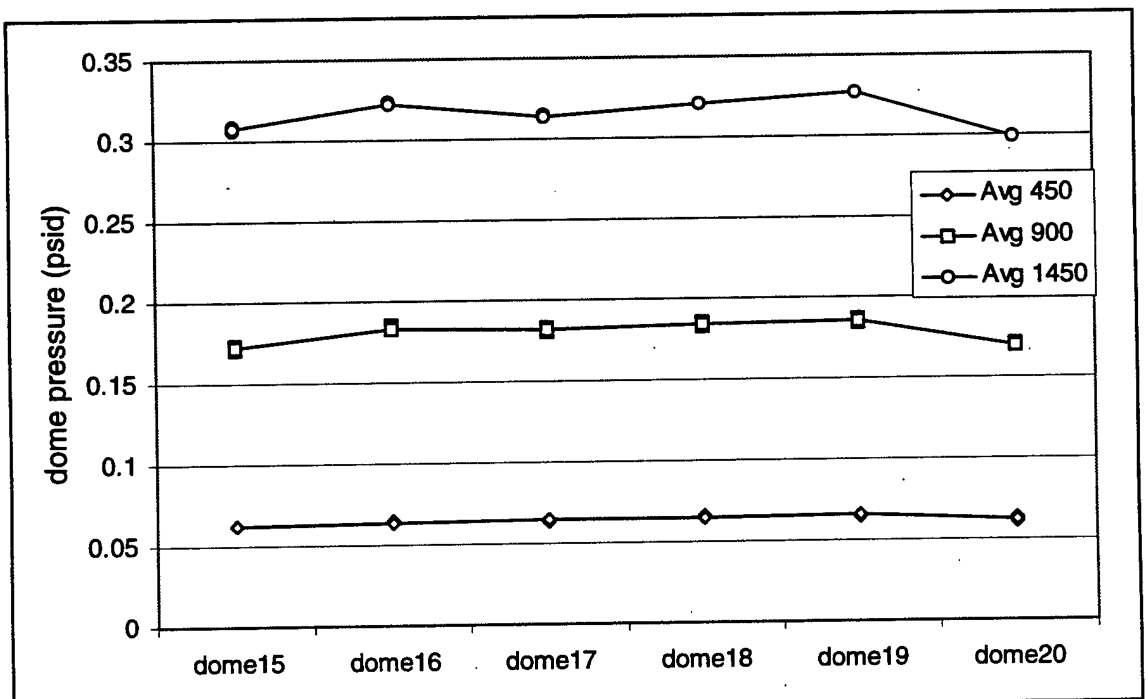

Figure 49. 'B' bank dome pressure for 3.1 second period at various blower speeds (rpm).

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